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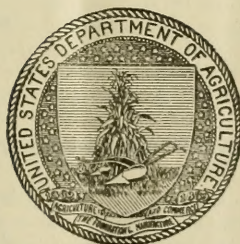
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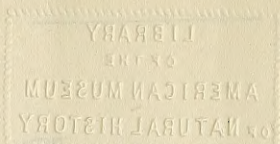
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UNITED STATES DEPARTMENT OF AGRICULTURE



BULLETIN No. 951

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JOHN R. MOHLER, Chief



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METHODS FOR CLOSE AUTOMATIC CONTROL OF INCUBATING TEMPERATURES IN LABORATORIES.

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The automatic control of temperature within close limits is very important in many lines of commercial work. It is of special importance, in fact, is a necessity, in laboratories where chemical, bacteriological, and physiological investigations are conducted. In many instances success in the maintenance of cultures depends upon the ability continuously to maintain practically constant temperature. Pathogenic microorganisms, as a rule, do not grow except within very narrow temperature limits, the optimum temperature being about 37.5° C. (99.5° F.).

The Bureau of Animal Industry, United States Department of Agriculture, produces tuberculin on a large scale; about 16,000 culture flasks of 300 c. c. capacity are maintained to produce the required quantity. The tubercle bacillus is very sensitive to temperature changes. In order to obtain the best growths, therefore, the temperature during the period of incubation should be maintained practically constant at the optimum of about 37.5° C. To hold the temperature in all parts of the chamber approximately constant requires considerable care, especially if the chamber is large.

Other work carried on by the bureau includes the study, by bacteriological means, of other diseases of domestic animals. The

cultures made from the diseased tissues are usually incubated at about the same temperature as that mentioned for the tubercle bacillus. There are, however, certain thermophilic organisms that may be encountered in bacteriological investigations of diseased tissues, and in order to be able to investigate these organisms smaller compartments are provided. These are located inside the larger incubating compartment and are furnished with separate heating devices. The system used for controlling the temperature is identical with that of the larger room, the controlling device being adjusted to maintain the temperature at a higher point.

CONSTRUCTION OF TEMPERATURE-CONTROL COMPARTMENT.

In the control of temperatures the proper construction of the compartment is of equal importance with that of the controlling apparatus. The walls, floors, and ceiling should be so constructed as to minimize the transfer of heat from the inside to the outside of the room, thus economizing on the quantity of heat required to maintain the desired room temperature. Not only will the proper construction of the room reduce the quantity of heat necessary to maintain the desired temperature, but should the supply of heat be discontinued the insulated walls of the room will assist in holding the temperature near the desired point for a considerable time. Figure 1 shows the rate at which the temperature falls when the source of heat is entirely cut off. The curve shows that for a period of approximately one week the drop in temperature was only about 6° C. The temperature surrounding the incubator room—that is, the temperature in the laboratory during this time—averaged about 21.1° C. It is obvious, therefore, that in a well-installed compartment cultures may continue to grow several days after the supply of heat has been discontinued.

The dimensions and construction of incubating compartments used in laboratories of the bureau at Washington are illustrated in figure 2. The finished inside dimensions of the rooms are 7 feet wide by 7 feet 6½ inches deep by 8 feet 5 inches high. The capacity of each room, in terms of standard 300 c. c. flasks, is about 2,600. In all there are 7 rooms of these dimensions.

CONSTRUCTION OF ROOM.

Floors.—On the laboratory floor one course of 1-inch cork board was laid down in hot asphalt. All transverse joints were broken and all joints were slushed with hot asphalt and made tight by butting the sheets of cork board closely together. The top surface of the cork board was flooded with hot asphalt about one-eighth inch thick, and directly on top of this a wearing concrete floor was laid, the thickness of the floor being 2 inches in the center of the room and 3 inches

at the walls. The floor was sloped to the center to facilitate cleaning and disinfecting.

Walls and ceiling.—Expanded-metal walls and ceiling were constructed, as shown in figure 2. These consisted of 1-inch channel studs, tied at the floor and ceiling and thoroughly crosstied. The studs were covered with No. 24 gauge high-rib expanded-metal laths which were used instead of channels in order to give greater strength.

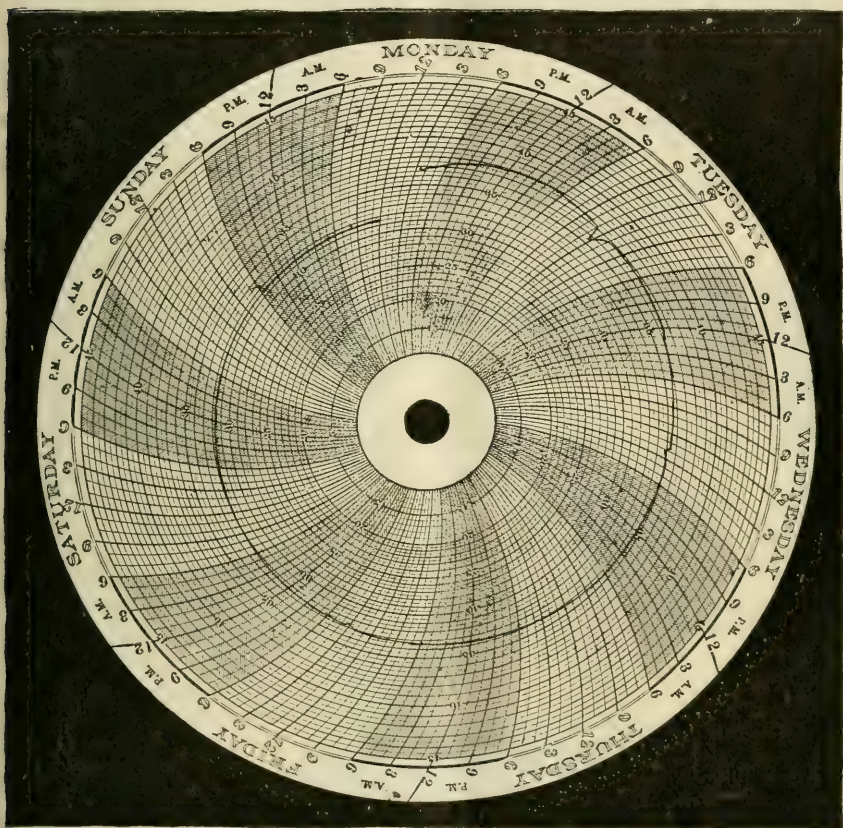


FIG. 1.—Chart showing drop in room temperature for one week, with heat supply entirely shut off.

Directly on the expanded metal a $\frac{1}{2}$ -inch course of cement mortar was applied, mixed in the proportion of 1 part of Portland cement to 2 parts clean, sharp sand.

While the mortar was green a course of 2-inch cork board was erected on it and the joints were slushed with hot asphalt. Against the exposed surface of the cork board a Portland-cement plaster finish about one-half inch in thickness was applied in two coats. The first coat, about one-fourth inch in thickness, was mixed in the

flasks are of the same size and fit on the pipe frame. Where different-sized crates are used, however, the wire covering is advisable.

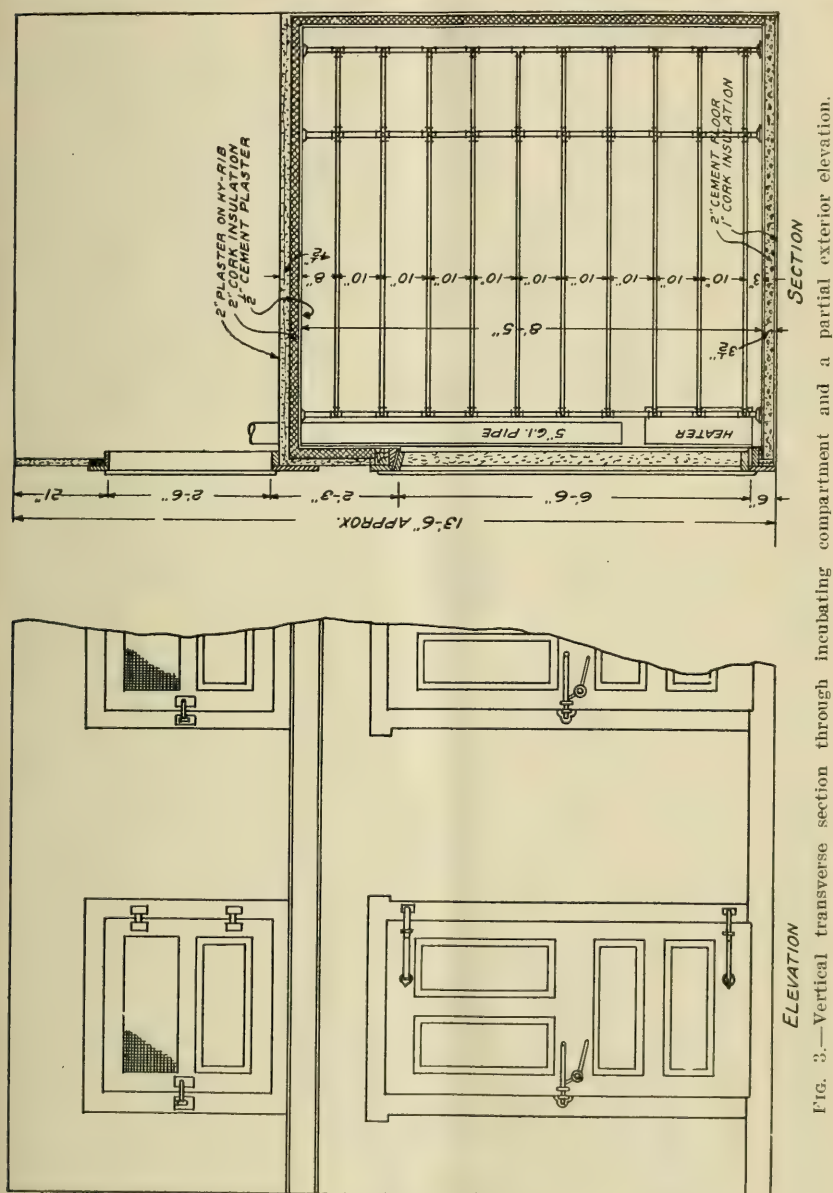


Fig. 3.—Vertical transverse section through incubating compartment and a partial exterior elevation.

HEATING EQUIPMENT.

Electricity is used in all cases as the heating medium. Two systems of temperature control, however, are used. The temperature-control

apparatus for the first incubating compartment was designed and for the most part constructed in the bureau. The temperature-control

system for the other compartment consists largely of assembled commercial apparatus.

The heating units consist of resistance tubes or coils fed from a 220-volt, direct-current line. The electric current is turned on and off the resistance units by means of a thermostat in the incubator compartment. The thermostat is adjusted to turn the electric current on and off with a variation of room temperature of 1° C., that is, 0.5° above and 0.5° below the optimum. It is possible to adjust the thermostat to turn the electric current on and off between much closer limits, but the limits of 0.5° above and 0.5° below the optimum temperature give satisfactory results, and the frequency of operation and hence the wear on the controlling apparatus are decreased. The temperature-control equipment

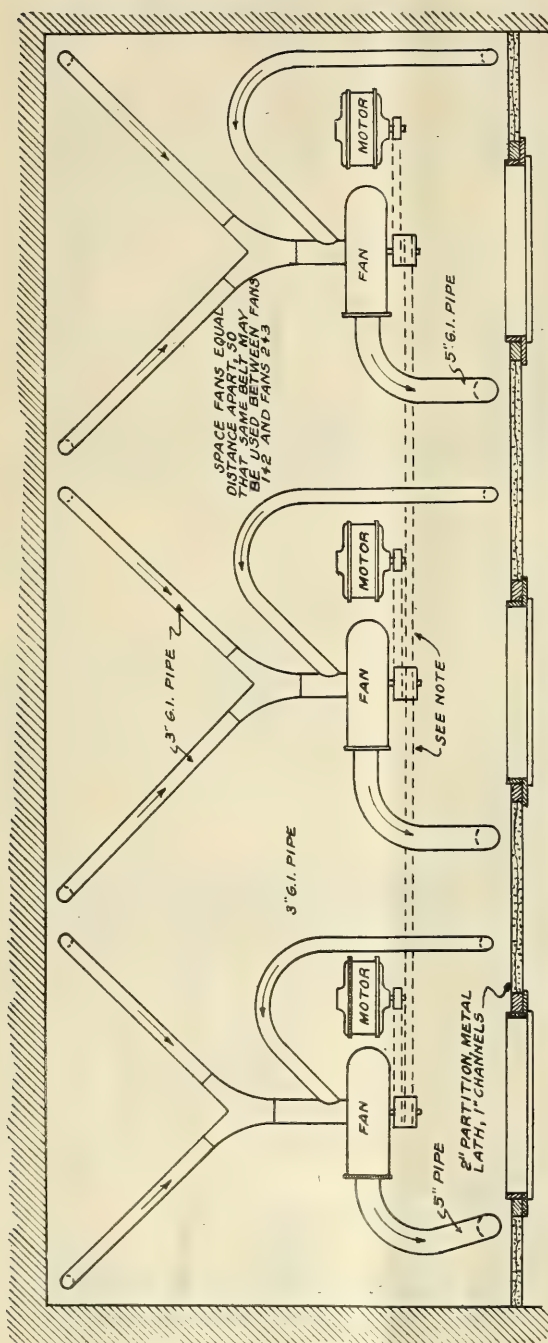


Fig. 4.—Plan of air-circulatory system installed over incubating compartment.

designed by the bureau demonstrated on tests that the temperature inside the room could be maintained between limits of $\pm 0.1^{\circ}$ C.

In order that all parts of the room may be kept at approximately the same temperature it is necessary to provide means for thoroughly and continuously stirring the air in the room. This is accomplished by an electrically driven fan, as shown in figure 4, with the piping so arranged that the air is blown down over the heating coils in one corner of the room and drawn from near the floor at the opposite corner and from the top of the room at the other two corners. With this arrangement the air is stirred thoroughly and the temperature is maintained approximately the same in all parts of the room. Since it is necessary to operate the fan continuously it is belt-driven at about half-normal speed, or at a speed that will insure a thorough mixing of the air and hence a uniform temperature. By using an oversize fan and operating it at reduced speed the chances of a breakdown of this important part of the equipment are greatly lessened.

The fans used in these installations operate at a speed of about 1,400 R. P. M. and deliver about 190 cubic feet of air a minute, or about 26 complete changes of air in the room every hour. The motors are shunt-wound, 230-volt, direct current. Two sizes of motors are used. Where a single motor drives two circulating fans a one-half horsepower motor is used, and where a motor drives only one fan a one-fourth-horsepower motor is used. The motor power is much in excess of that actually required to drive the fans; but since they operate continually and receive little attention, it is advisable to have considerably more power than is actually required.

DESCRIPTION OF TEMPERATURE-CONTROL SYSTEMS.

A general view of the temperature-control board, which was designed and constructed in the bureau, is shown in figure 5, and a diagram of the system is shown in figure 6. The electrical connections covering the motor for driving the fan are simple and require no explanation.

In the temperature-control system proper there are four coils of 110 ohms each. Two of the coils are connected in series and directly across the main line, with a switch for cutting the coils out if desired. In cold weather the coils are brought into service. They are so proportioned that when continuously in service they will maintain the temperature in the room slightly below the point desired. The other two coils, which are connected in series, furnish the additional heat required to bring the temperature of the room up to the desired point. The latter two coils are connected to and operated by the controlling system. These coils are connected through the relay to the other side of the 220-volt line through a variable resistance in series with the instrument. This resistance is sufficient to reduce the voltage in

the relay circuit to four volts, and thus prevent arcking and burning the thermostat and relay contacts. Condensers are placed in the circuits where shown (fig. 6) for the purpose of absorbing the inductive discharge from the coils when the circuits are broken.

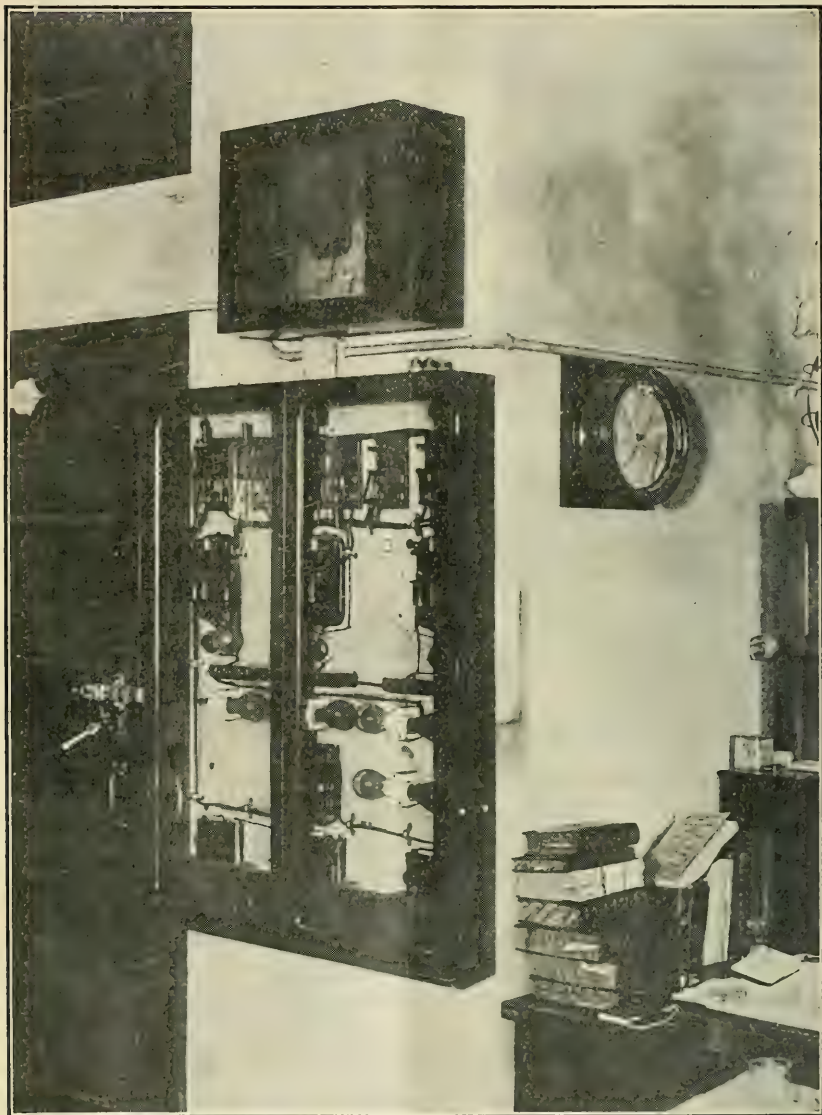


FIG. 5.—Temperature-control board of incubating room in Pathological Division:

The relay is connected for reverse action; that is, when the electric circuit is completed through the thermostat, owing to rising temperature in the room, the relay operates to break the main heating-coil circuit and thus cut off the supply of heat. On the other hand, when the relay circuit is broken in the thermostat, owing to a lowering

temperature in the room, the relay closes the heating-coil circuit. The overload device, shown in the diagram, has for its object the cutting out of the whole system in case the temperature-control apparatus fails to operate. In principle it is identical with the tempera-

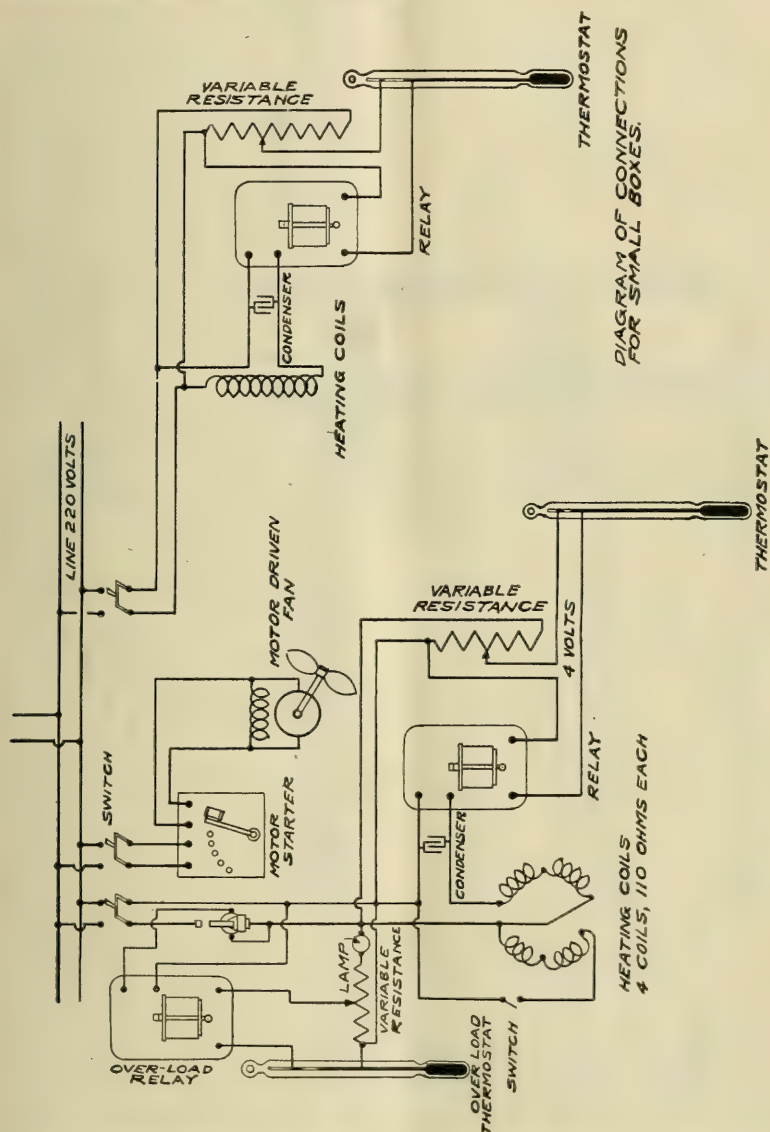


FIG. 6. — Wiring diagram of Pathological Division temperature-control system.

ture-control equipment. The overload thermostat is adjusted to close the electric circuit through the overload relay at a room temperature a few degrees above the normal operating temperature, the relay in turn breaking the circuit through the overload coil in the main line, thus cutting off the electric current in the entire system.

is maintained only a few degrees above that of the surrounding air, only small-capacity resistance units are required.

The special thermostat used in the incubator room is shown in figure 8. It is capable of making and breaking the electric circuit on a variation in temperature of about $1/100$ of a degree F. Temperature adjustments are made by transferring mercury from the small reservoir to the capillary tube, and vice versa.

A general view of the temperature-control boards made up of commercial apparatus is shown in figure 9, and a diagram of the electric connections in figure 10. Six rooms are equipped with this apparatus. Referring to the diagram (figure 10), one side of the line is connected directly to the heating coil and from the heating coil to the line-magnet coil. The current in this coil is controlled by the pilot coil, which in turn is controlled by the thermostat. When the pilot circuit is closed through the thermostat the pilot coil is energized and closes the circuit through

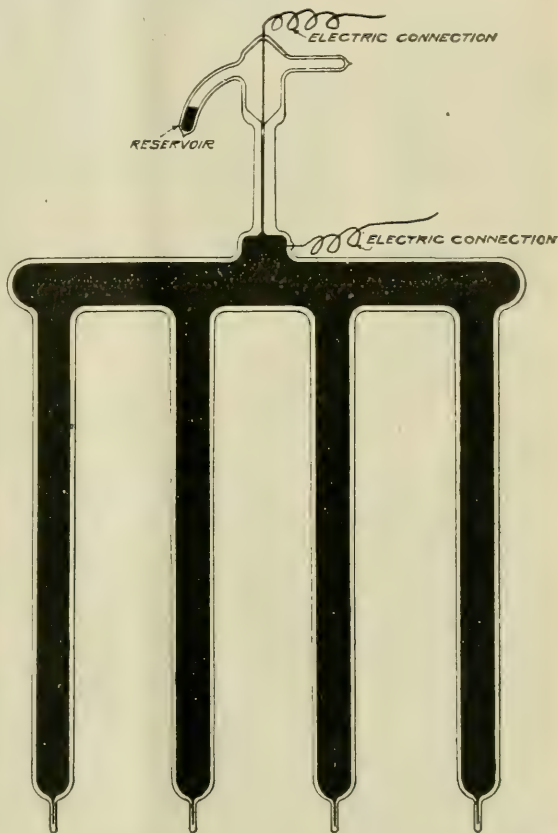


FIG. 8.—Mercury thermostat used in temperature-control system of Pathological Division.

the line coil, which acts to close the line circuit through the heating coils. When the temperature in the incubation room rises to the upper limit the thermostat makes contact with the stop point, thus breaking the pilot circuit and opening the line coil, and hence the current in the heating coils.

TEMPERATURE RECORDERS.

Each incubation room is fitted with a continuous 7-day recording thermometer. The recording elements are mounted on the wall outside the room and the capillary passes through the wall, the bulb

being located near the top and in the center of the room. The charts taken from the recorders are examined and any variations in temperature beyond the prescribed limits are noted with the time at which the variations occurred. With these data at hand it is nearly always possible to find the cause of an excessive variation in tem-

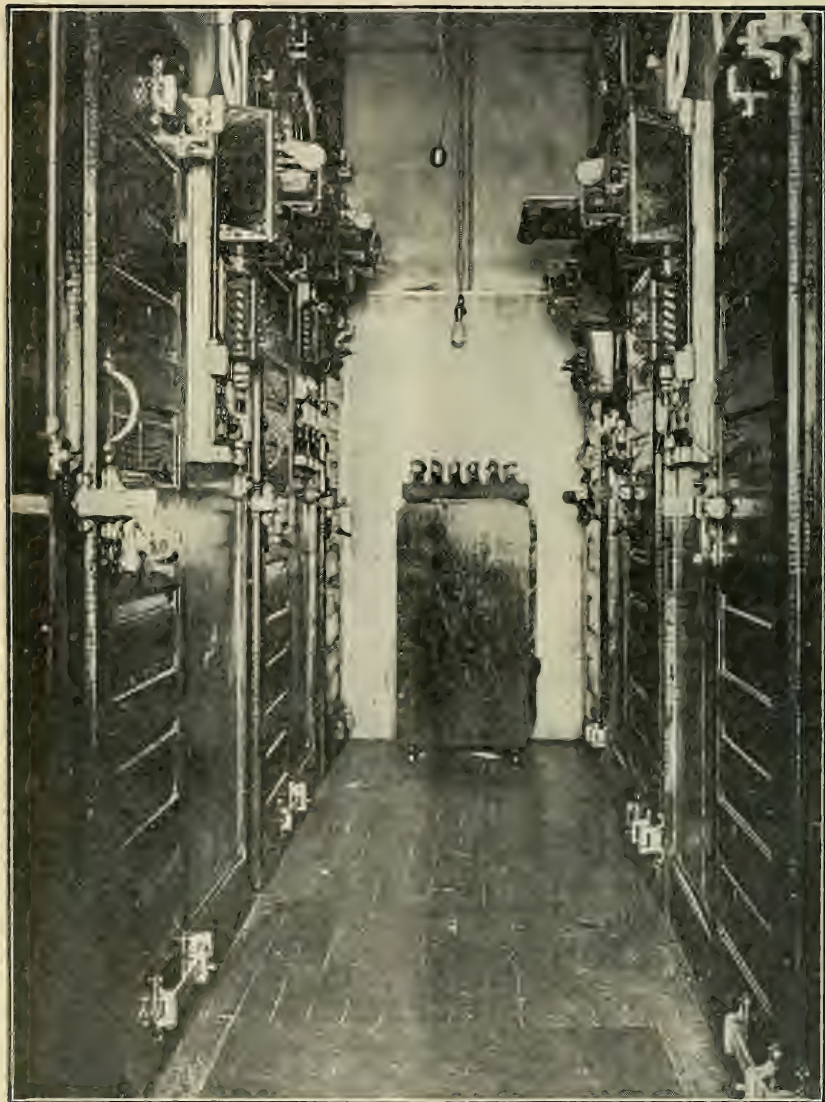


FIG. 9.—The temperature-control boards used by the Biochemic Division.

perature and also to fix the responsibility, if any is due. The mere fact that a permanent, continuous, and exact record is kept of the temperature conditions inside the incubator room is a stimulus to those in charge to do their best to maintain the conditions desired.

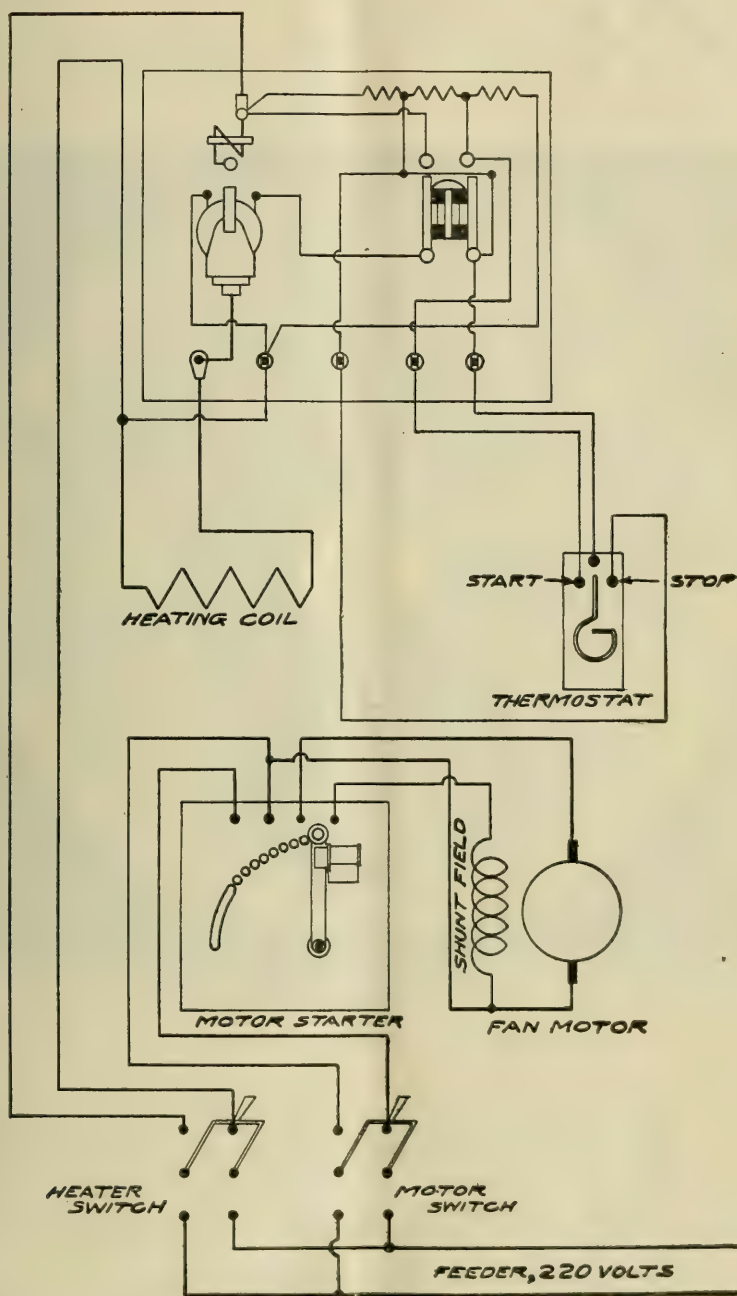


FIG. 10.—Wiring diagram of temperature-control system in Biochemical Division.

The value of a continuous-temperature record in the process of incubating cultures is great. Such records are not only of value in showing the temperature at all times throughout the period of incubation, but they may be dated and filed for reference, thus making it possible to determine with accuracy the temperature maintained in the incubating process on any previous date.

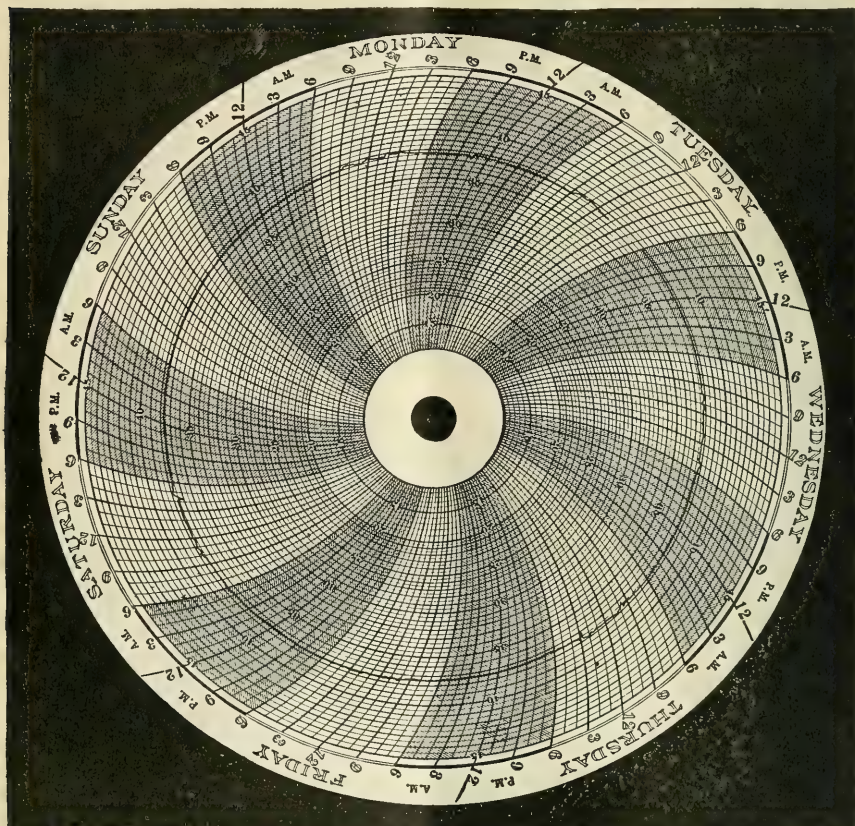


FIG. 11.—Chart showing the temperature maintained in the incubating room of the Pathological Division, January 22 to 29, 1918. Note that night temperatures especially are practically without fluctuation.

The chart in figure 11, taken from the incubator room equipped with the temperature-control system designed in the bureau, shows the temperature maintained for the week January 22 to 29, 1918—typical of the winter season. Attention is invited to the fact that during the night periods, when the room is closed, there is scarcely any variation in the temperature. During the day periods, however, when the door is opened for storing or taking out specimens, temperature variations occur. But in no instance do the variations exceed 1°C ., and they exist for only a few minutes at a time. Even

these temperature variations may be materially lessened if the door is quickly opened and closed and kept closed while storing or removing specimens. A similar chart, figure 12, covering the week August 6 to 13, 1918, shows the results obtained during a typical summer period. The incubator room was entered only about twice during this week; consequently the temperature was maintained practically constant throughout the period.

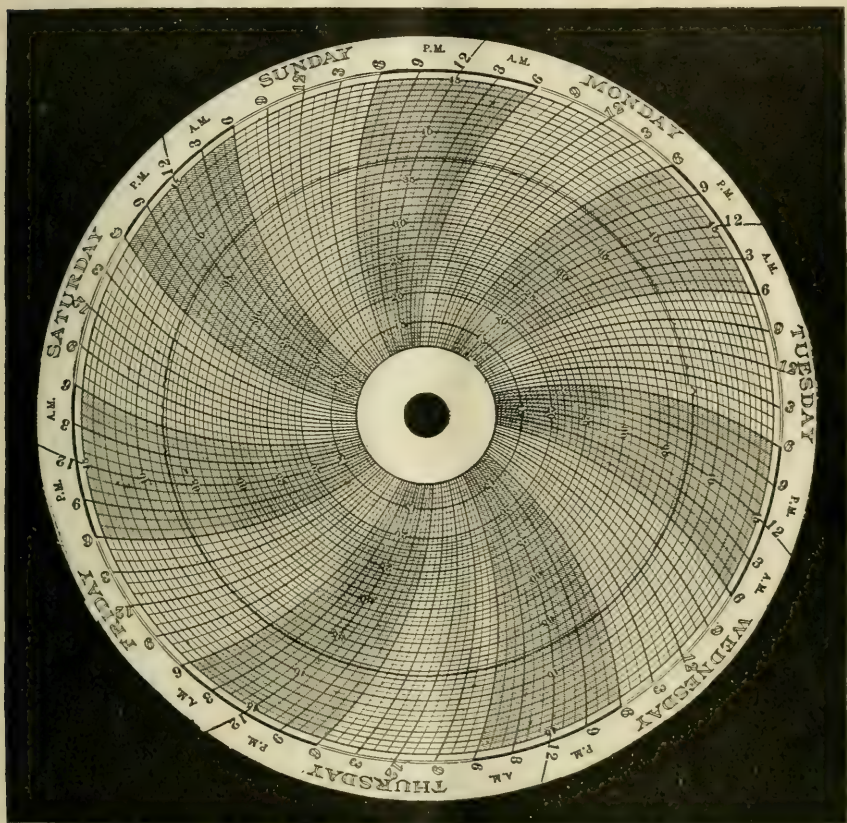


FIG. 12.—Chart showing temperatures maintained in incubating room of Pathological Division, August 6 to 13, 1918. Note that variations are exceedingly small.

The chart in figure 13 was taken in one of the incubator rooms equipped with a control system made up largely of assembled commercial apparatus. The curve shows that while the average temperature was about that for which the control was adjusted it was not so uniform as the temperatures shown in the previous charts. While this latter temperature-control system is not so sensitive or reliable as the former, and hence requires closer attention and more frequent adjustments, it has the advantage of being assembled from commercial apparatus.

COST OF OPERATION.

The cost of electric energy for operating the heating equipment and the motor-driven circulation fan at 6 cents a kilowatt hour averages about 50 cents a day of 24 hours for each room.

Prior to the installation of the present incubating rooms a large number of gas-heated incubators were used, the temperature being controlled by means of a bimetallic thermostat which regulated the

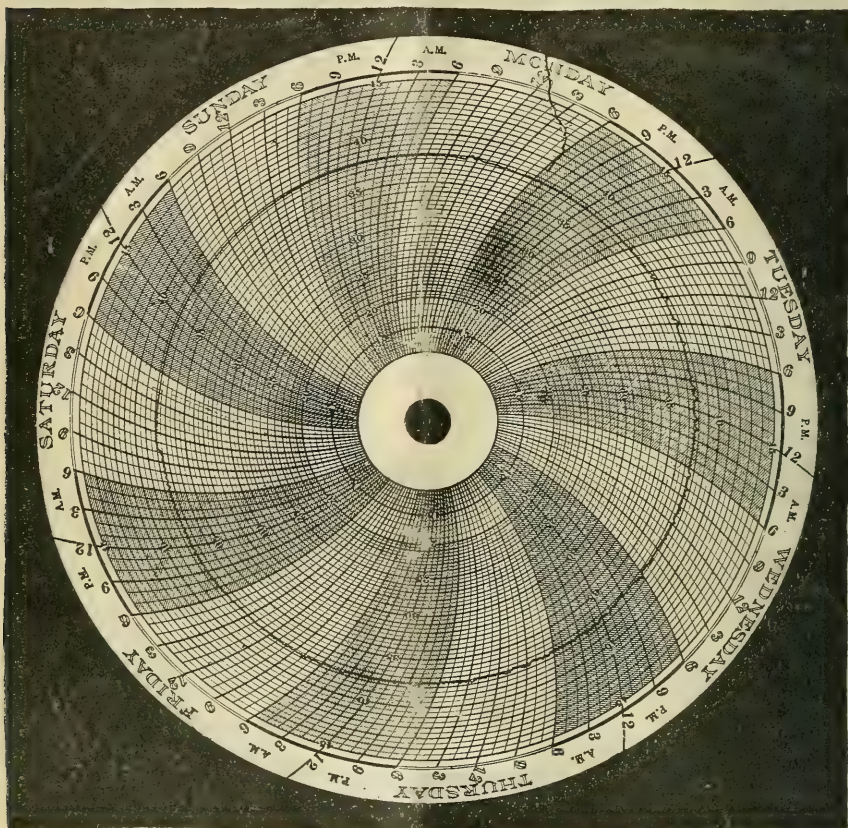


FIG. 13.—Chart of temperature maintained in incubating room, Biochemic Division, April 7 to 14, 1919. The system of control used is not so sensitive as that used in the Pathological Division.

flow of gas. These incubators occupied a large floor space, the control of temperatures was poor, and the fire hazard was great. With the present installation of incubating rooms the capacity has been about doubled and the space occupied has been reduced about one-half. Furthermore, the cultures have grown better than ever before, a result mainly of the very uniform temperature which has been maintained in the incubating rooms.

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COMMERCIAL UTILIZATION OF GRAPE POMACE AND STEMS FROM THE GRAPE-JUICE INDUS- TRY.¹

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THE CONSERVATION OF FRUIT-PRODUCT WASTES.

FOR MANY YEARS the cultivation of grapes for the production of grape juice has been an industry of large and growing proportions, and with the increasing popularity of the juice as a beverage the industry has received added impetus. In the process of preparing the juice for market large quantities of stems and pomace result, which at present are practically waste material.

In several publications of the United States Department of Agriculture (13, 14, 15, 16)² it has been shown that in preparing products for market from such fruits as cherries, raisins, peaches, apricots, and tomatoes the waste resulting from the various processes is capa-

¹ The writers wish to express their thanks to Mr. J. D. McIntyre, Chemical Laboratorian of the Office of Drug, Poisonous, and Oil Plant Investigations, for valuable assistance rendered during the course of this investigation.

² The serial numbers in parentheses refer to "Literature cited" at the end of this bulletin.

ble of being converted into products of considerable value. The waste resulting from the grape-juice industry offers like possibilities.

ACCUMULATION AND PRESENT DISPOSAL OF GRAPE WASTE.

In the manufacture of grape juice the grapes are first passed through a so-called stemmer, which removes the stems and discharges them to a conveyor or chute, which in turn carries them to the dump heap as waste (fig. 1). Immediately following this operation, the grapes, more or less crushed, are heated to about 140° or 145° F., thoroughly agitated to insure homogeneity of the mass, then wrapped in heavy press cloths and placed in hydraulic presses between wooden racks. After the juice has been pressed out the pomace which remains



FIG. 1.—Waste grape stems.

in the cloths is approximately 1 inch in thickness and 4 feet square. This pomace, stripped of the cloths, is discharged to conveyors, which usually carry it also to the dump heap (fig. 2).

The pomace has been used in a small way for fertilizer purposes and to a limited extent by vinegar manufacturers. It has been used by some to make a second or low grade grape juice by soaking with water and pressing again and has also been fermented into wine. The water extract of the pomace has been used to flavor jelly.

Commercial interests in the United States have given some attention to the disposal of grape waste with a view to its profitable utilization, but thus far no complete utilization of both stems and pomace has resulted from the attempts made, and the disposal of this waste is at present an item of expense rather than one of profit.

In some other countries considerable attention has been given to the utilization of grape residues resulting from the wine industry. In 1907 Semichon (18) called attention to the feeding value of dried grape marc based on its protein, fat, and carbohydrate content. In the same year Bertainchand (2, 19) reported on the utilization of grape marc for the feeding of farm animals. He condemned its use as a fertilizer, because of its value when mixed with molasses as a feeding stuff for cattle and sheep. Paris (12) has investigated grape residues in Italy, stating that if the seeds contained in the marc were utilized for oil an annual production of 18,000 liters could be obtained. The fresh marc is said to contain 25 to 30 per cent stems, 50 to 60 per cent fibrous tissue, and 15 to 20 per cent seeds. Grape-seed cake was stated by Fuchs (6) to contain 12 per cent protein, 5



FIG. 2.—Waste grape pomace.

per cent fat, and 33 per cent nitrogen-free extract; but because of the great quantity of crude fiber its value as a stock food is diminished. Daza (4) and Disdier (5) patented processes in 1914 for treating grape marc for the production of various useful products, such as oil, alcohol, tannin, and potassium bitartrate. Further work of similar nature on the utilization of grape residues is mentioned by De Saporta (17) and Matignon (8).

During the war Kling (7), in a report on new feeding stuffs used in Germany, stated that grape pips, containing 10 per cent protein, 7 per cent fat, 29.5 per cent fiber, and 35.1 per cent nitrogen-free extract, have a nutritive value corresponding to that of medium-quality meadow hay.

In 1916 Monti (10) reported a process for extracting grape pomace. During the same year a statement was made (11) to the effect that

grape seed can be used as a fodder, but apparently only for sheep. It is also noted that the Austrian Ministry of Commerce (1) called attention to the use of grape seed as a raw material for the production of oil, oil cake, and meal, the latter to be used as a stock food.

In 1917 Matignon and Marchal (9), in addition to investigating grape pulp for fertilizer and food value, called attention to the possible fuel value of this waste, which, from the wine industry of France, would be equivalent to 160,000 tons of coal. In 1918 Ventre (20) further called attention to the utilization of grape seeds in France for the extraction of edible oil. In 1915 Dawson (3) reported on the manufacture of oil from grape seeds in Argentina.

AVAILABLE QUANTITY OF GRAPE WASTE.

In order to estimate the available quantity of waste resulting from the manufacture of grape juice, questionnaires were sent to manufacturers in the grape belt, extending from Michigan across upper Ohio and into central New York. The figures submitted gave the tonnage of grapes crushed from 1914 to 1918, inclusive, and from these an average has been taken to represent the quantity which may be expected annually.

The waste consists of stems and pomace, the latter being made up of the skins and seeds. The stems are calculated as 3 per cent of the original grapes and the pomace as 20 per cent. The skins constitute about 75 per cent of the wet pomace (containing 50 per cent of moisture) and the seed 25 per cent. From these calculations the following figures were obtained, which may be taken as representing the approximate quantities of the waste materials which result annually from the grape-juice industry in the grape belt under consideration:

	Tons.
Total quantity of grapes crushed.....	22,000
Stems (3 per cent of the grapes).....	660
Wet pomace (20 per cent of the grapes).....	4,400
Skins (75 per cent of the wet pomace).....	3,300
Seed (25 per cent of the wet pomace).....	1,100

COMMERCIAL PRODUCTS OBTAINABLE FROM GRAPE WASTE.

The stems, which occur as the first by-product, contain cream of tartar and tannin, both of which may be obtained in the same operation.

The pomace, which constitutes the second and larger portion of the waste, consists of skins and seeds in about equal parts when dry. From the skins, which contain much flavor, color, and pectin, a palatable jelly can be made. From the seeds can be obtained oil, meal, and tannin extract, the most important of which is perhaps the

oil, the meal and tannin extract being of secondary importance in point of actual value. The diagram (fig. 3) illustrates the reduction of this waste material to the various commercial products mentioned.

CREAM OF TARTAR FROM GRAPE STEMS.

The method of extracting the cream of tartar from the stems consisted in boiling the ground stems with an excess of water, running off the water extract, and concentrating it at atmospheric pressure or by means of a vacuum pan to the consistency of a thin sirup. When allowed to stand, this extract deposited crystals of cream of tartar, which were thrown on a force filter or into a centrifuge and washed with cold water, in which the crystals are only slightly soluble. In this manner about 2 per cent of crude cream of tartar was obtained. The washed crystals were readily purified by recrystallization from a hot-water solution.

The total quantity of wet stems (660 tons) would yield, therefore, about 13.2 tons of crude cream of tartar, which, at 40 cents a pound (a conservative figure for the crude crystals), would bring a gross revenue of \$10,560.³

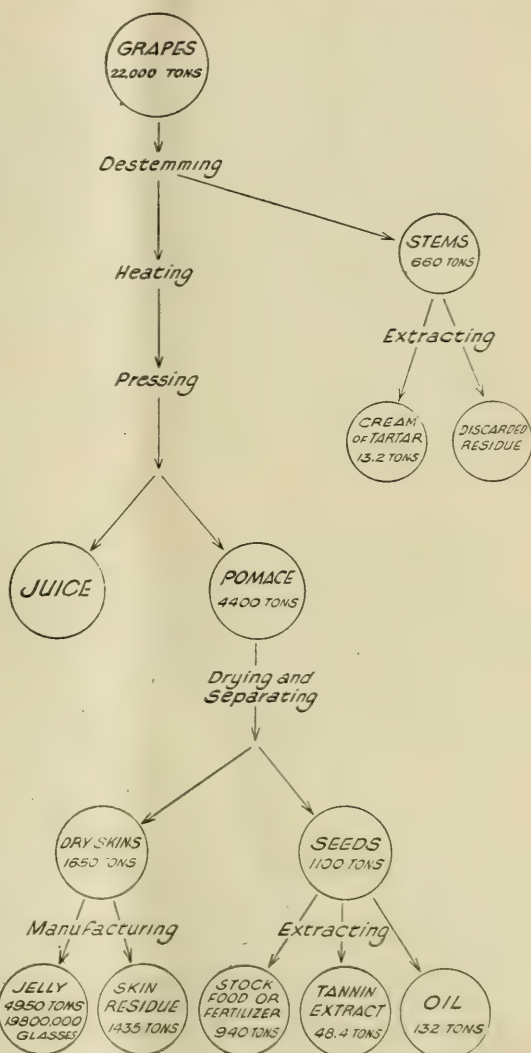


FIG. 3.—Diagram showing the products obtainable from grape waste.

³ All estimates and prices quoted hereinafter, unless otherwise specified, are based on prices obtaining in the winter of 1919-20.

The tannin content in the mother liquid from which the cream of tartar was crystallized was found to be too low to be considered as a commercial product.

PREPARATION OF GRAPE POMACE FOR THE MANUFACTURE OF JELLY AND OIL.

Scarcely enough pomace is produced at any one factory to pay the individual plant for the immediate utilization of both skins and seeds. Since, however, the pomace as it is produced contains about 50 per cent of moisture, which is conducive to rapid spoilage, attention was directed along the line of preparing this wet pomace in such a way as to permit it to be stored and manufactured later into the various products or to be shipped to some central utilization plant which could handle the entire output from the several grape-juice plants.

A plant handling even a comparatively small tonnage of grapes could perhaps work up the skins into jelly at a good profit, but it could not profitably extract the oil from the seed, since for this purpose a large, comparatively expensive oil mill would be required.

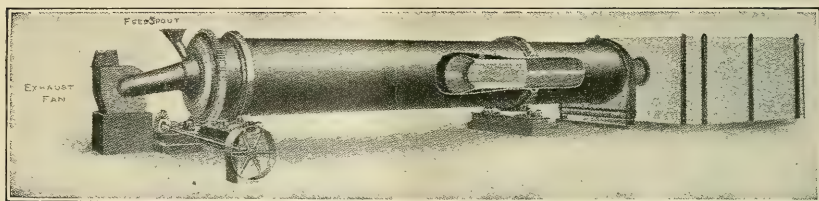


FIG. 4.—A direct-heat drier.

To extract the jelly stock from the skins they must first be boiled in a small quantity of water and then pressed in hydraulic presses. This would necessitate either the installing of additional presses or the reducing of the quantity of grapes handled; in the latter case the output of juice would be curtailed. Experiment has proved that the pomace can be satisfactorily dried, the seeds and skins separated, and each worked up as desired. There would thus be no curtailment of the output of juice because of reduction in the quantity of grapes handled, nor would there be any added expense incurred for installing additional presses.

The pomace may be dried by means of driers of the direct-heat type (fig. 4) or the steam type (fig. 5). In either case the wet pomace should be disintegrated and conveyed into the machine in a continuous stream. Both driers rotate on a horizontal axis. The material enters the driers at one end in a continuous stream and passes out at the other end in a dry condition. The heated air current enters at the discharge end and leaves at the entering end, thus working on the counter-current principle. The two types of

driers differ only in the sources and method of application of the heat. Both are continuous in operation. Such procedure in

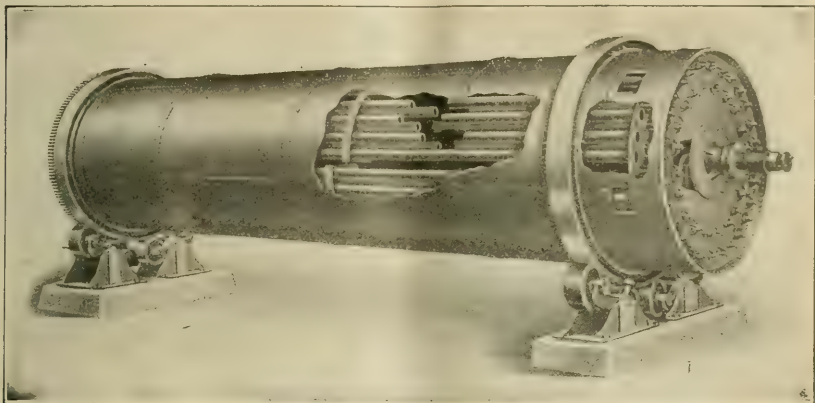


FIG. 5.—A steam-type drier.

all cases can be carried out by the individual plant, since the outlay is comparatively small. The skins and seeds may be separated and bagged for storing immediately upon issuing from the

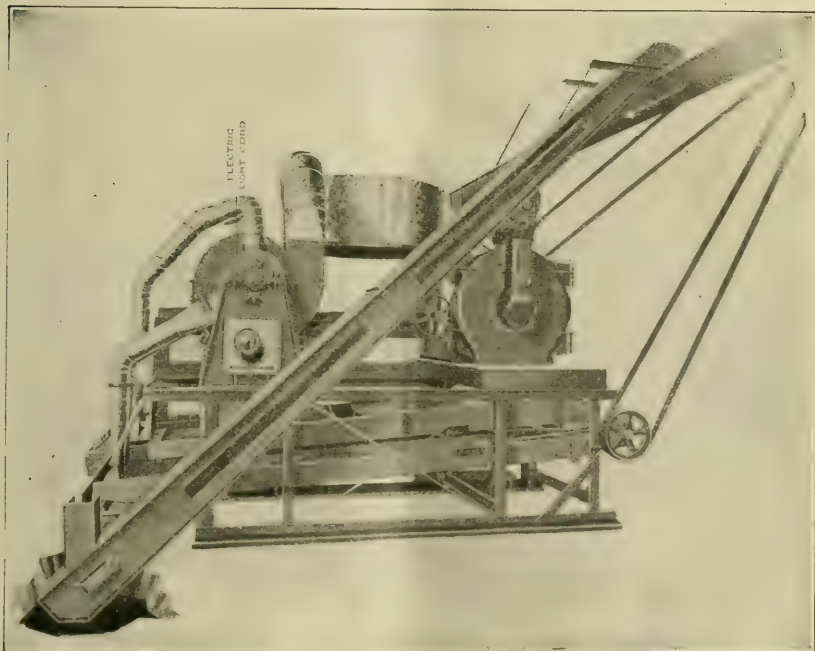


FIG. 6.—A hulling and separating machine.

drier. A hulling and separating system which consists essentially of an elevator, grinder, shaking sieves, and blower, as shown in figure 6, is well adapted for this purpose. The masses of seeds and

skins from the driers are conveyed to the elevator of the hulling and separating system, thence to the grinder, where the seeds and skins are thoroughly disintegrated and drop upon the shaking screens, effecting a partial separation. Final separation is accomplished by means of the blower attachment.

If it should be desired to separate the seed from the pomace before drying, the wet pomace passes through an ordinary pomace picker

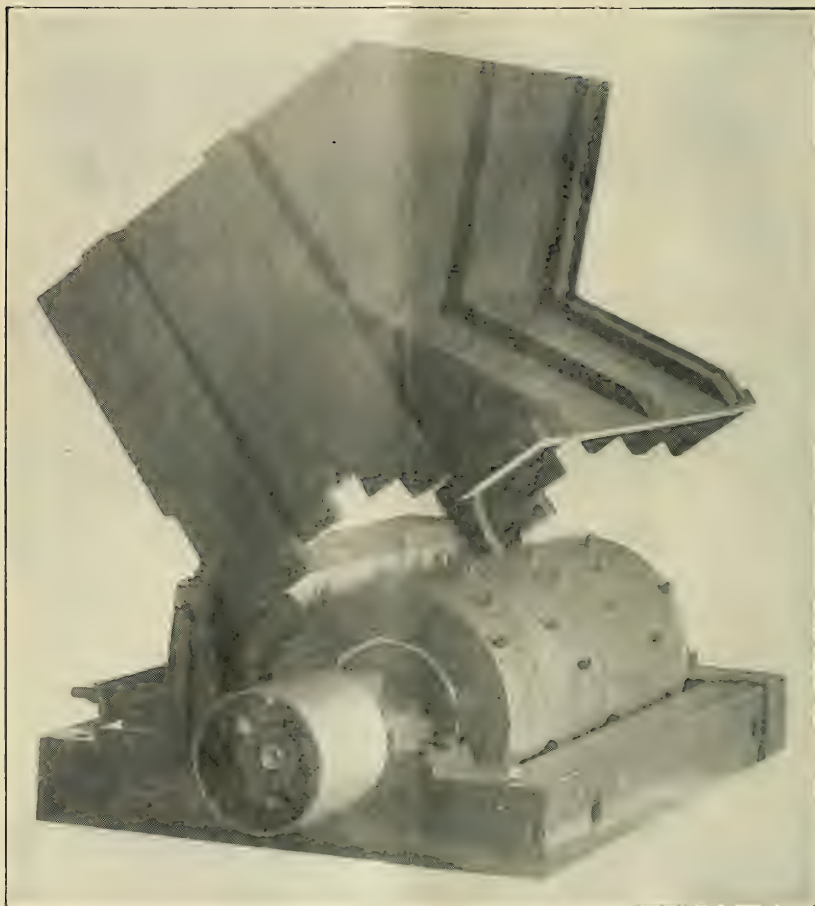


FIG. 7.—A pomace picker.

(fig. 7), then into an apple grater (fig. 8), thence into a fanning mill or other seed-separating machine, and from there into the drier. The pomace picker consists of rotating drums with projecting teeth. These teeth break up the pomace, but not sufficiently to release all of the seed. For this reason the pomace is put into the apple grater, which reduces it to smaller pieces and thus releases more of the seed. The seed and skins may then be effectively separated either by

passing the disintegrated pomace into a shaking and fanning mill, such as is ordinarily used in cleaning grain and seed, or into a rotary separator similar to a sand cleaner, but provided with a quarter-inch mesh, that the seeds may fall through. The seeds are conducted

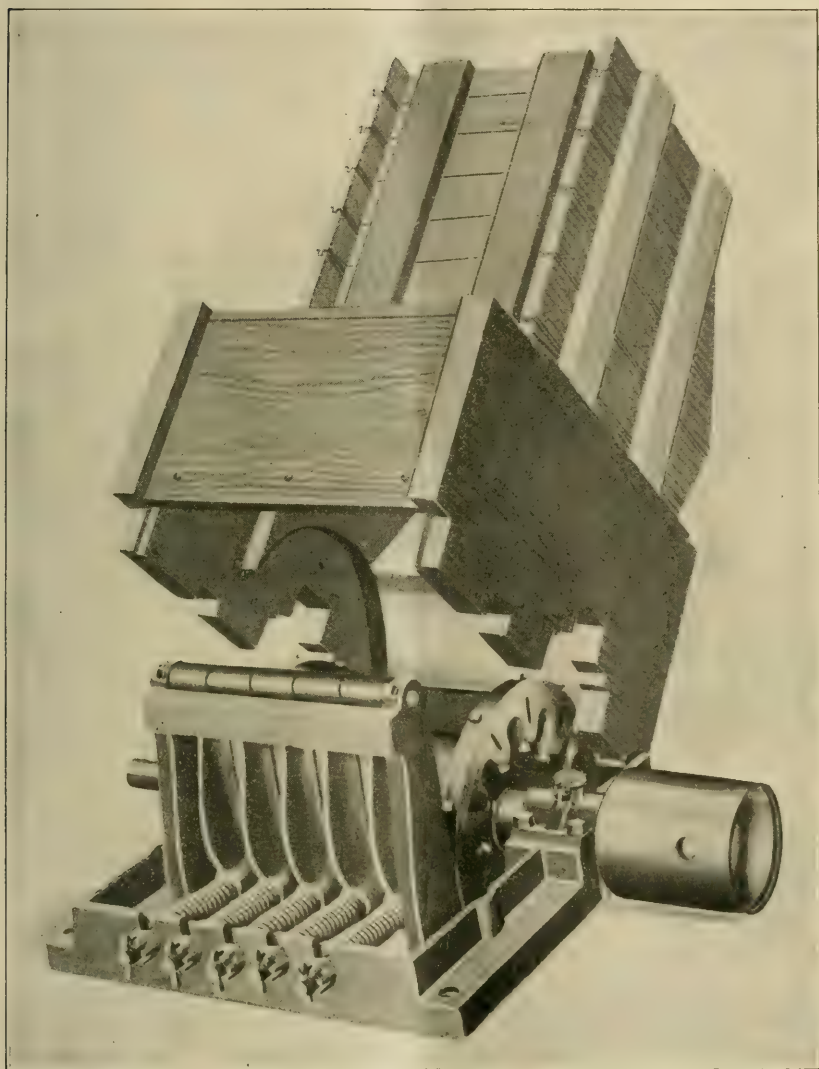


FIG. 8.—An apple grater.

out just as is the gravel in cleaning sand. In either machine, however, about 7 to 10 per cent of the total quantity of seed originally in the pomace is lost. Since the seed contains more than 13 per cent of moisture, it must be dried before storing or shipping; otherwise it would mold and spoil. In this connection it is of interest

to note that in separating the seed from the wet pomace, particularly when it is effected in a fan separator, about 3 to 5 per cent of moisture (calculated on the total weight of the pomace) is removed, due to the aeration of the fanning operation.

A much better separation of the skins and seeds can be effected, however, after the pomace is dried, and it is therefore not considered advisable to make the separation before drying unless the wet pomace is to be worked up immediately, which can be done only where the plant producing it has all the facilities necessary for the purpose or where some plant engaged in utilizing such products is near enough to receive the pomace promptly. In the latter case the profitableness would be determined by the cost of hauling, giving due recognition to the fact that the fresh pomace contains 50 per cent of moisture, which would bear its proportionate cost of transportation.

In handling the pomace as it is produced from the presses the method outlined insures a minimum charge for labor and supervision. It is evident that by means of conveyors no handling of the pomace is involved after it is stripped of the press cloths until it is discharged from the driers. Bagging machines and conveyors would contribute to the continuity of the operation, but it is questionable whether the quantity of material handled would pay for the additional equipment necessary. A thermometer could be attached to the steam drier, so that there would be no risk of burning, but in case the boiler capacity of a plant were bearing its full load during the grape-pressing season there would not be sufficient steam available to operate the steam drier. In that event it would be necessary to resort to the direct-heat drier, requiring rather careful supervision.

MAKING JELLY FROM GRAPE SKINS.

To make jelly from the waste grape skins they are placed in a large wooden tank, in the bottom of which is an open steam pipe shaped like a cross. Enough water is added to cover the pipes, and the steam is turned on until the mass boils violently. The boiling should not be continued longer than 15 minutes, preferably about 10 minutes, depending, however, upon the quantity of material and the ease with which it can be handled. If boiled too long the jellifying property is destroyed, and if boiled too short a time the result is an insufficient solution of the jellifying property (pectin). If boiled too slowly some parts of the mass are overheated and others underheated, causing a low yield. The mass is then pressed in ordinary hydraulic presses, similar to those used in pressing out grape juice or in making cider. If the jelly is made by the plant which produces the pomace, the same presses can be used that were earlier used for making the grape juice.

In the manufacture of jelly it is absolutely necessary that the jellifying strength of a given juice be fairly accurately known, on account of the interdependence of the percentage content of the pectin, sugar, acid, and water. Varying the quantity of any one of these may cause the difference between good and poor jelly from the standpoints of texture and taste. It should always be recognized that it is impossible to determine the character of the resulting jelly until it has cooled under ordinary atmospheric conditions. Usually the results of a given procedure are not known until the following day.

The pectin is controlled by varying the quantity of juice used. The sugar should be increased or decreased as is found necessary for the given quantity of juice. Too little sugar produces tough, rubbery jelly, while too much produces soft jelly. To ascertain the best proportion of sugar to use to a given quantity of juice, it is recommended that a known weight of the pomace be cooked with the same relative quantity of water that is regularly used in the process of jelly manufacture. Add dissolved tartaric acid to the juice in the proportion of 1 ounce of acid to 1 gallon of juice. Divide this juice into equal portions of 1 pint each. For each pint use, respectively, one-fourth, one-half, three-fourths, and 1 pound of sugar. Cook to 224° F., pour into jelly glasses, and set aside undisturbed until the next day. The boiling should be done over a good flame and in a vessel large enough to take care of the excessive foaming.

These samples should be concentrated within 20 minutes, since long, slow boiling destroys the jellifying qualities. The jelly that presents the best texture is the one to adopt as the standard. However, the relative quantities of sugar and juice should be confirmed by making a larger batch, since results obtained from small quantities are not always the same when applied to large commercial runs.

Any kind of sugar, whether cane, beet, or one of the corn sugars, such as glucose and the like, may be used.

All jelly should possess more or less acidity. Jelly of the best quality possesses an acidity of approximately 0.75 per cent (expressed as tartaric acid). Too little acidity results in soft jelly; too great an acidity also produces soft jelly, because it destroys the jellifying properties of the juice during the boiling operation. Since most of the acid in the grapes is removed with the juice, it is necessary to add tartaric acid to restore the acidity sufficiently to establish the proper ratio for satisfactory jelly. In all cases the acid should be dissolved in the smallest possible quantity of water and added to the boiling mass; otherwise it may not readily go into solution.

The water content, of course, is regulated by the extent to which the mass is evaporated and is best determined by the boiling tem-

perature, the optimum temperature for good commercial jelly being 222° to 224° F. The housewife usually produces thinner jelly with a materially lower boiling point. In view of these facts it is apparent that it is not advisable to add too much water because of the prolonged boiling which is necessary to remove it.

Grape jelly foams exceedingly when it nears the jelly point, and ample accommodations should be left to take care of the volume of foam. This is most readily accomplished by using a low-jacketed kettle and insuring ample steam pressure.

Attention is also called to the fact that it is preferable to make the jelly in small quantities of 10 to 25 gallons rather than in quantities of 50 to 150 gallons, the common American practice. It is generally recognized that a product of higher grade can thus be obtained, since a smaller quantity means a greater percentage of heating area to the volume than is the case with larger quantities. This is due to the fact that as the quantity of liquid in a hemispherical kettle is increased the volume increases as the cube of the radius, while the surface exposed to the heat increases only as the square of the radius. Thus, there is a greater concentration of heat per unit of volume in the smaller quantity, with attendant quicker boiling.

It may be of general interest to point out that it is perfectly feasible to make good jelly by substituting some of the popular glucose sirups for granulated sugar. Such jelly, of course, is not as sweet as that made with the sugar, but this can be obviated by decreasing the quantity of tartaric acid added in the earlier stages or by using a mixture of equal parts of cane or beet sugar and glucose. It should be remembered, however, that commercial glucose contains approximately 30 per cent of water, and therefore a proportionately greater quantity by weight should be used than of sugar.

The phenomenon of crystallization attendant upon making grape jelly is one with which all housewives and jelly technologists are familiar. This is due to the slow precipitation of crystals of cream of tartar in the jelly during long standing, because of the insolubility of the crystals. Various means are used in the grape-jelly industry to obviate this. Some add alkali to the juice in order to convert the cream of tartar into potassium tartrate, which is more soluble in the jelly than the cream of tartar, and consequently there is much less tendency to crystallization. Others make jelly stock by boiling the grapes in a small quantity of water and canning the concentrated product for future use. Upon standing, the crystals of cream of tartar slowly settle to the bottom, and when the time comes to make the jelly the juice can be poured off from the settlings (argols). By this means crystallization in the jelly is reduced to a minimum.

Jelly made from grape skins contains only a minimum quantity of cream of tartar, since most of this has been removed with the juice; consequently, there is less tendency to granulation than in jelly made from the whole grapes. Jellies which were made in the laboratory from grape skins in the fall of 1919 were still free from crystals in the summer of 1920.

Ash determinations, which bear strongly on this point, showed 0.15 per cent of ash in the jelly made from grape skins, while that made from the whole grapes from the same section of the country showed 0.31 per cent. This is another indication that the cream of tartar content in the case of jelly from grape skins is lower than in that from the whole grapes.

Those who would not care to make jelly from the refuse skins could can the jelly stock and sell it to jelly manufacturers or to housewives. However, it is thought that this stock, upon standing, might become gradually weaker in its power of gelatinization, a fact recognized by jelly technologists as occurring in apple-jelly stock.

That a good grade of jelly can be made from grape skins is nothing new in itself. Many housewives make good jelly from the pomace resulting from homemade grape juice, and field experiences in the summer of 1919 disclosed the fact that in New Jersey many persons were securing the pomace from grape-juice manufacturers for this purpose.

QUANTITY AND VALUE OF JELLY AND RESIDUE.

As previously estimated, 4,400 tons of wet pomace result annually from the grape-juice industry, of which 3,300 tons are wet skins. The results of the experiments conducted, indicate that at least three 8-ounce glasses of jelly can be made from each pound of wet skins. Calculating on this basis, there could be manufactured from the total available annual supply of wet skins about 19,800,000 8-ounce glasses of jelly.

Grape jelly now appears on the market in three forms: (1) Pure grape jelly, made from the whole grapes; (2) apple-base grape jelly, made from a mixture of grape juice and apple juice; and (3) grape apple-pectin jelly, made from jelly stock strengthened in its jellifying properties by the addition of commercial apple-pectin stock. The prices of these products vary greatly. Pure grape jelly sold at wholesale in January, 1921, for \$2.70 a dozen 8-ounce glasses, and some of it retailed for 30 cents a glass. Apple-base grape jelly and pectin grape jelly sold at wholesale for about \$1.40 a dozen glasses, retailing at about 15 cents a glass.

As a basis for a comparison of prices, it may be stated that in January, 1921, apple jelly sold at wholesale for about \$1.40 a dozen

8-ounce glasses, retailing at about 15 cents a glass. The price of dry apple pomace in January, 1921, was $2\frac{1}{2}$ cents a pound; on this basis grape pomace should cost about a cent less. Since the only other ingredient is sugar, it follows that the prices of the two finished products should be approximately the same.

There should be no difficulty in marketing this jelly, since grape jelly is well liked, and the reason it does not fill a greater place in the dietary is largely on account of the high price. If, therefore, grape skins are utilized for this purpose it is evident that the jelly could be sold about as cheaply as apple jelly and yet return a satisfactory profit. The wholesale value of the total quantity of jelly capable of being manufactured from the grape skins available annually (3,300 tons) would be more than \$2,000,000.

The net profit in handling grape waste will vary according to the plan of utilization adopted. These plans may be stated as follows:

- (1) To separate the seed from the wet pomace at each factory, sell the seed, and manufacture the jelly immediately from the wet skins.
- (2) To dry the pomace, separate and sell the seed, and manufacture the jelly from the dry skins during the season when the presses would otherwise be idle.
- (3) To dry the pomace, separate the seed and skins, and sell both.

Plan No. 1.—Since 1 dozen glasses of jelly can be made from about 4 pounds of wet skins, 1,000 tons of grapes (producing 150 tons of wet skins) would yield approximately 75,000 dozen 8-ounce glasses. At a selling price of \$1.50 a dozen the gross returns would be \$112,500. The cost to manufacture this quantity of jelly (which will be given in detail later) amounts to \$87,000, leaving a net profit on the jelly of \$25,500. A thousand tons of grapes produces about 50 tons of seed, which would bring approximately \$500. The total profit, therefore, in plan No. 1 would be \$26,000.

Plan No. 2.—As in plan No. 1, the yield of jelly from 1,000 tons of grapes would be approximately 75,000 dozen glasses and the gross returns the same, \$112,500. To the cost for manufacturing the jelly (\$87,000) must be added that for drying and bagging the pomace (200 tons), which is approximately \$1,800, making the total cost \$88,000. The net profit on the jelly in this case would therefore be \$23,700. Here again the seed would bring approximately \$500, making a total profit in plan No. 2 of \$24,200.

Although plan No. 2 is not quite as profitable as plan No. 1, it is far more practicable, since it utilizes the presses during the winter months when otherwise they would be idle.

Plan No. 3.—Here the pomace is dried and both seed and skins are sold, so that no cost for manufacture is involved. The dry skins, delivered at a utilization center (jelly factory), would bring about \$24 a ton. This includes \$9 a ton for drying and \$5 a ton for hauling, leaving a net profit of \$10 a ton, which on 75 tons of dried skins (150 tons of wet skins) would equal \$750. To this must be

added the value of the seed (\$500), making the total profit in plan No. 3 \$1,250.

If the seed were all assembled at a central cooperative plant and manufactured into oil a greater profit could be realized by the producers.

The residue remaining from the manufacture of the jelly was investigated for its possible value as a stock food. After drying and reducing to meal it was found to have approximately the following composition, indicating excellent stock-feeding qualities:

	Per cent.
Protein	11.06
Ether extract	7.87
Nitrogen-free extract	59.92
Crude fiber	21.24

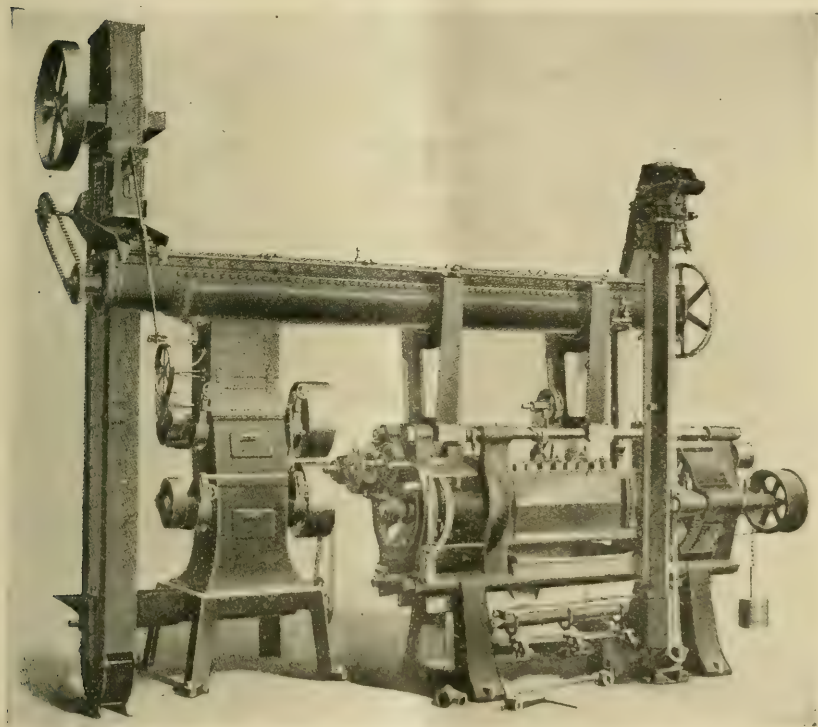


FIG. 9.—A 1-expeller type of press.

The total quantity of dry residue would be approximately 1,435 tons, which, valued at \$17 a ton, would bring a gross return of \$24,395.

MANUFACTURE OF OIL FROM GRAPE SEEDS.

Two methods of oil recovery are employed in extracting the oil from grape seeds: (1) The pressure method and (2) the solvent-extraction method.

The most economical pressure method is by means of the expeller type of press (fig. 9). The ground seed is fed continuously into the

hopper, where a horizontal rotating screw carries the charge forward and subjects it to great pressure by discharging it over a cone in the throat of the horizontal barrel containing the charge and screw. The oil drips from openings in the barrel and the cake or chips are discharged from the throat.

Owing to the comparatively low oil content of the seed (13 per cent) and also to the very hard seed coat, which tends to cause excessive wear on the expeller, it is desirable that the seed be first decorticated. Thus, a large part of the hard hulls may be removed and the oil content of the kernels be more readily obtained. The resulting cake has also a much lower fiber content than if the whole seeds were passed through the expeller.

In the laboratory a successful decortication was effected by passing the seed through a vertical-plate mill set for medium to coarse grinding. The ground mass of seeds was then passed through a rotary sifter (of the flour-sifter type) fitted with No. 20 wire mesh. This produced a separation of the coarser particles of the shells or hulls from the finer meaty portion of the seeds. The hulls were found to constitute 44 per cent of the seeds and the kernels with some of the finer particles of shells 56 per cent. The hulls showed an oil content of 4.07 per cent and the kernels 19.9 per cent.

The kernels were now in condition to permit the oil to be readily extracted, and the shells were in such small quantity as to have only a minimum wearing effect upon the expeller. The yield of oil obtained from the kernels was about 14.5 per cent. This oil was of a dark-green color and had a strong nutlike odor and taste. After being refined it was straw colored with a slight greenish tint and pleasant bland taste and smell.

Solvent extraction of any oleaginous material depends upon the solubility of the oil in some volatile solvent, such as benzol. When dry ground grape seeds are treated with a warm benzol solution the latter dissolves the oil, which is then separated from the solution by distillation of the solvent. The recovery of the solvent from the solution is thus effected, enabling it to be used repeatedly. The extracted residue is treated with steam to remove the traces of benzol. By this method from 11 to 12 per cent of oil may be obtained. Such a solvent-extraction plant is shown in figure 10.

The crude grape-seed oil which was obtained by this method was refined and yielded an oil equal in quality to that obtained by pressure.

It will readily be recognized that each of these methods has both advantages and disadvantages. The solvent-extraction method produces a greater total yield of oil than the pressure method, but the oil cake resulting from the pressure method possesses valuable stock-feeding qualities which would enable it to be sold to better advantage

than the resulting meal from the solvent extraction. The latter contains a large percentage of fiber, which practically precludes its use as a feeding material, and it could be used only as a fertilizer.

EXTRACTING TANNIN FROM THE HULLS.

The astringency of grape seeds is well known. This is due to the tannin in the hulls, which is present to such an extent as to affect unfavorably the stock-feeding value.

In order to determine the quantity of tannin obtainable from the hulls the ground hulls were macerated with water at 35° to 40° C. for

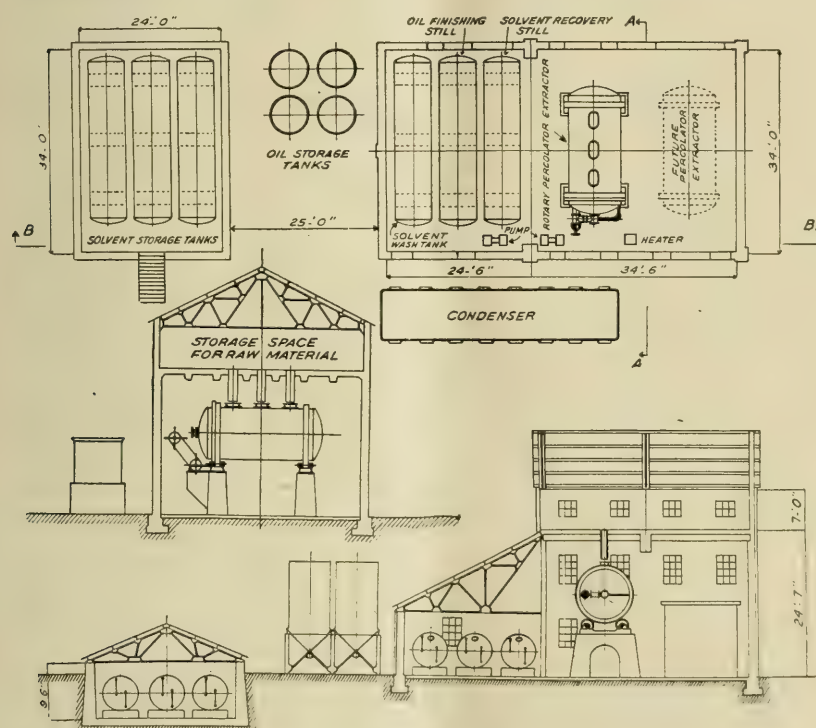


FIG. 10.—Oil-extraction plant, with rotary percolator extractors.

12 hours, then percolated, and the extract concentrated in vacuo. By this means 10 per cent of a soft extract was obtained, which showed 47.5 per cent total solids, 45.2 per cent soluble acids, 2 to 3 per cent insolubles, 15.5 per cent tannin, and 29.7 per cent nontannin.

This extract was submitted to a large tannery for testing, and the results of the test on leather showed good tannage with excellent color.

In view of the present need for tannin extracts, it appears probable that the hulls resulting from the decortication of grape seeds could be thus utilized. The total quantity of hulls available would

be about 484 tons, which would yield 48.4 tons of tannin extract, or 96,800 pounds. Based on the analysis and behavior of the extract in tanning, a value of 3 cents a pound may be considered a conservative figure. The gross returns of this extract, therefore, would be \$2,904.

QUANTITY, USES, AND VALUE OF THE OIL, OIL CAKE, AND TANNIN EXTRACT FROM GRAPE SEEDS.

Grape-seed oil is semidrying in character and possesses qualities similar to those of soy-bean and cottonseed oils. In commerce it should find ready application as an edible oil, or as a soap, paint, or varnish oil. Based on these facts, it should have an equal value with these oils. The pressed oil should bring about 17 cents a pound (the price of soy-bean oil in December, 1919). Extracted oil usually brings 1 or 2 cents less a pound.

The press cake from the decorticated seed contains 4.48 per cent fat, 14 per cent protein, 29.7 per cent nitrogen-free extract, and 43.2 per cent crude fiber, and should find use as an excellent stock food, comparing favorably with such feeding stuffs as sunflower seeds, cottonseed, coconut cake, palm-nut cake, timothy hay, and alfalfa hay. Based on the value of these common feeding stuffs, the value of the press cake can conservatively be figured at \$30 a ton.

The undecorticated meal from the solvent-extraction process contains a much higher content of fiber and tannin and a much lower content of fat and could probably not be figured at more than \$12 a ton. If the seed were decorticated, as in the expeller operation, the meal should bring about \$25 a ton.

The quantities and gross value of the expeller oil, oil cake, and tannin extract, or the solvent oil and meal, capable of being manufactured from the total annual output of grape seeds are presented in Table I.

TABLE I.—Quantities and gross value of products capable of being manufactured from grape seeds by the expeller and solvent processes.

Process and product.	Quantity (tons).	Value.
Expeller process:		
Seeds available.....	1,100	
Kernels (56 per cent of seeds).....	616	
Oil (14.5 per cent yield, at 17 cents a pound).....	89.3	\$30,362
Oil cake (at \$30 a ton).....	526.7	15,801
Hulls (44 per cent of seeds).....	484	
Tannin extract (10 per cent) from hulls, at 3 cents a pound.....	48.4	2,904
Total value.....		49,067
Solvent process:		
Seeds available.....	1,100	
Oil (12 per cent yield, at 15 cents a pound).....	132	39,600
Meal (at \$12 a ton).....	968	11,616
Total value.....		51,216

Since it was deemed more practicable to assemble the waste material at some utilization center and there work it up into merchantable products, several widely separated points were selected which would represent the maximum range of ready-assembling stations, and also their importance from the standpoint of working up waste materials from other industries. Table II gives the estimated cost of assembling the waste at several selected points. The freight rates represent car lots wherever possible and are given for shipping the whole pomace and the seed alone.

TABLE II.—*Estimated cost of assembling the dry grape pomace or the seed alone at various selected points for utilization centers.*

Waste, and shipping State.	Quantity (tons).	Cost of shipment to—			
		Chicago, Ill.	Indianapo- lis, Ind.	Philadel- phia, Pa.	Westfield, N. Y.
Pomace:					
Michigan.....	750	\$2,583.00	\$3,092.00	\$6,914.00	\$3,870.00
New York.....	1,160	6,912.00	6,784.00	6,060.00	1,781.00
Ohio.....	290	1,390.00	1,325.00	1,903.00	1,110.00
Total.....	2,200	10,885.00	11,201.00	14,877.00	6,761.00
Average per ton.....		4.95	5.09	6.76	3.08
Seed:					
Michigan.....	274	1,292.00	1,546.00	3,457.00	1,936.00
New York.....	580	3,498.00	3,433.00	3,060.00	929.00
Ohio.....	145	713.00	668.00	949.00	581.00
Total.....	1,100	5,503.00	5,647.00	7,466.00	3,446.00
Average per ton.....		5.00	5.14	6.79	3.13

The operating costs may be divided into two general groups: (1) Those pertaining to drying the pomace, with the separation and bagging of the seed, and (2) those concerned with working up the material into the finished products.

The charges against drying the pomace and separating and bagging the seed may be itemized as follows:

Depreciation on equipment, 10 per cent.....	\$600
Power, 5 tons coal at \$6 for 20 days.....	600
Labor, 2 laborers at 40 cents an hour, for 20 days of 24 hours each.....	384
Bags, 1,000 at 20 cents each.....	200

Total cost for drying and bagging..... 1,784

These figures cover the cost for handling the pomace of a plant crushing 1,000 tons of grapes for a season of 20 days and represent the charge on 200 tons of wet pomace dried to 100 tons containing 20 per cent of moisture. One ton of dried and bagged pomace costs, therefore, approximately \$18.

The cost for making and packing 1 dozen glasses of jelly has been estimated as follows:

Labor, power, depreciation.....	\$0.10
Glasses and labels.....	.25
Pomace (cost of drying).....	.03
Sugar (at 12 cents a pound).....	.53
Boxes	.15
Overhead	.10
Total	1.16

Since the skins from 1,000 tons of grapes produce 75,000 dozen glasses of jelly, the total cost for making and packing this quantity of jelly would be \$87,000.

Inasmuch as this investigation is concerned with utilizing a material which has heretofore been discarded as waste, it follows that the same plant, management, and selling force which handles the main line (grape-juice) could take over the jelly manufacture with comparatively little extra expense for overhead charges. Consequently, this item is low. Approved accounting would, of course, demand that this product assume its share of the general manufacturing expense. But since such cost distribution would result in a greater profit from the grape-juice end and would thus be certain to appear on the books sooner or later, it is, for the sake of ready comparison, credited to the utilization of the waste.

An oil-extraction plant which could handle 25 tons of seed in a 24-hour day would cost approximately \$25,000, not including the building. The total charge against this would be about \$10 a ton, including the charges for depreciation, labor, power, and management. Only about 33 days would be consumed in working up this seed; hence, it would be necessary to work up other products during the remainder of the year in order to have these prices obtain. If the seed were extracted in a larger plant which was engaged at times in the extraction of other material, the cost would be considerably reduced. The cost to expel the oil would be about \$13 a ton, figured on the same tonnage as the above.

GROSS RETURNS AND NET PROFITS FROM THE UNDERTAKING.

In order to show approximately the gross returns and net profits which may be expected from the manufacture of grape waste into commercial products, Table III has been compiled.

From these figures two totals are obtained, depending upon the method used for extracting the oil from the seeds. Solvent extraction produces oil and meal, whereas extraction by pressure produces oil, oil cake, and tannin extract. From the solvent method the total gross returns are \$2,559,138 and from the pressure method \$2,557,005.

TABLE III.—*Approximate values and estimated gross returns obtainable from the manufacture of various products from grape waste by different methods.*

Material used and product obtained.	Quantities obtained.		Approximate values.	
	Solvent method.	Pressure method.	Solvent method.	Pressure method.
Skins:	<i>Glasses.</i>	<i>Glasses.</i>		
Jelly.....	19,800,000 <i>Tons.</i>	19,800,000 <i>Tons.</i>	\$2,475,000	\$2,475,000
Jelly residue.....	1,435	1,435	24,378	24,378
Stems:				
Cream of tartar.....	13.2	13.2	8,560	8,560
Seeds:				
Oil.....	132	89.3	39,600	30,362
Meal.....	968		11,600	
Oil cake.....		526.7		15,801
Tannin extract.....		484		2,904
Total gross returns.....			2,559,138	2,557,005

Process or product.	Unit of estimate.	Cost per unit.	Total cost.	
			Solvent method.	Pressure method.
Extracting cream of tartar (13.2 tons) from stems.....	Ton.....	\$30.00	\$396	\$396
Pomace (4,400 tons), local price.....	do.....	2.50	11,000	11,000
Drying and bagging pomace (4,400 tons).....	do.....	9.00	39,600	39,600
Hauling dried pomace (2,200 tons).....	do.....	5.00	11,000	11,000
Separating seed (1,100 tons) from pomace.....	do.....	3.00	3,300	3,300
Manufacturing jelly (1,650,000 dozen glasses) from the skins.....	Dozen.....	1.16	1,914,000	1,914,000
Drying and grinding jelly residue (1,435 tons).....	Ton.....	3.00	4,305	4,305
Extracting oil from seeds (1,100 tons).....	do.....	10.00	11,000	
Decorticating seeds (1,100 tons).....	do.....	4.00	4,400	4,400
Pressing oil from kernels (616 tons).....	do.....	13.00		8,008
Extracting tannin from hulls (484 tons).....	do.....	3.00		1,452
Total cost for manufacture.....			1,999,001	1,997,461
Net profits.....			560,153	559,544

Against the gross returns must be charged the cost of making the various products. In order to ascertain the costs involved in a rational utilization of the waste, all successive operations involved from the accumulation of the pomace to the finished products are included in the estimates. No charge is allowed for the cost of the raw material, since there is no way to estimate what this should be except as the value of the finished products is compared with the cost of producing them. Table III shows the cost per ton and the total cost of the various operations from the purchasing of the pomace to the products resulting from the waste. It will be seen that if the solvent method is employed the approximate total cost will be \$1,999,001, while by the pressure method the total cost is \$1,997,461, making the approximate net profits from the two methods \$560,153 and \$559,544, respectively.

In these calculations it is assumed that the waste is utilized at some central point and that all the products are manufactured from the waste. Only in this way is a minimum expense involved, since much of the necessary machinery can be utilized for the several op-

erations, thus reducing the cost of equipment and labor charge as well. If only a few of the products are manufactured, the profits would necessarily be reduced, since the cost of preparing the material would be distributed over a smaller number of products.

Complete utilization of grape waste for its full market value would be possible only when done at one point, since increased costs would mitigate against the success of the undertaking if attempted at several points with only a fraction of the total quantity of material available for reduction.

SUMMARY.

Since this investigation has shown that the waste which accumulates annually in large quantities at the various grape-juice plants can be made to yield a number of commercially valuable products, the utilization of this material should command the serious attention of manufacturers.

The possibilities have been pointed out and attention has been called to the proper and most economical methods for handling the waste. The procedure and methods of treating the stems, seeds, and skins for the production of cream of tartar, oil, oil cake, tannin extract, and jelly are most important from the standpoint of successful exploitation.

A careful study of the cost of the various operations involved in handling the waste and in manufacturing the products shows, by comparison with the returns, that profitable utilization is entirely possible.

It should be understood that all costs and returns, unless otherwise specified, were calculated on prices prevalent during the winter of 1919-20. Therefore fluctuations in prices and costs of freight, labor, machinery, and products must be given due consideration in the interpretation of the returns possible from an undertaking of this character.

With the growth of the grape-juice industry an increase in the quantity of waste will result. The more urgently, therefore, should be emphasized the necessity for utilizing this waste, both as an adjunct to the mother industry and as a reclamation project of agricultural and industrial importance.

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UNITED STATES DEPARTMENT OF AGRICULTURE



BULLETIN No. 953

Contribution from the Bureau of Animal Industry
JOHN R. MOHLER, Chief



Washington, D. C.

PROFESSIONAL PAPER

May 14, 1921

NITROGEN AND OTHER LOSSES DURING THE ENSILING OF CORN.

By R. H. SHAW, Chemist, and P. A. WRIGHT and E. F. DEYSHER, Assistant
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PURPOSE OF PAPER.

The silo is primarily a means for conserving food material. With the preservation through fermentation of the mass of corn or other crops in the silo there is generally the loss of a small amount of food material. Certain losses are apparently necessary in the proper fermentation; others are probably unnecessary.

For several years the Dairy Division has been studying to find out more definitely what losses incident to the ensiling of corn are necessary and what is the proper method of handling the crop to prevent such losses. This bulletin deals with the losses of nitrogen and other elements in corn silage made under ordinary farm conditions.

PREVIOUS INVESTIGATIONS.

The earliest recorded studies of the loss of nitrogen and other elements during the ensiling of corn were made with material very low in dry matter and stored in pit or tub silos.

Moser (1),¹ at the Vienna Agricultural Experiment Station, buried bundles of green maize, some wilted and some fresh, at different

¹ The figures in parentheses refer to the citations at the end of this bulletin.

depths in a small earth pit silo. Calculating on the basis of the author's tables, one notes losses as high as 74 per cent of the water content and 28 per cent of the crude protein of the original maize in the pit at a depth of 42 centimeters, but at a depth of 170 centimeters only a 3 per cent loss of water and a 7 per cent loss of the crude protein. His tables indicate a larger loss of nitrogen-free extract in the upper than in the lower layers and a gain in crude fat in the lower layers. The loss in crude fiber is small except in one sample. The change in ash content varies over a wide range.

Weiske and Schulze (2) report experiments in which they ensiled maize containing only 12 per cent dry matter. They used two watertight vats holding 125 kilos and 110 kilos, respectively. The first one, containing maize well packed in, lost 26.1 per cent of its dry matter and 37.8 per cent of its crude protein in 112 days. The second one, containing maize loosely thrown in, lost 35.8 per cent of its dry matter and 54.2 per cent of its crude protein in 115 days. Both tub silos lost heavily in crude fiber and nitrogen-free extract, but gained very markedly in ether extract.

Jordan (3) states that in the course of three years' work, using a stone-basement root cellar as a silo, he found only a 5.18 per cent to 11.82 per cent loss of organic matter, which appeared to be almost wholly in the carbohydrates other than crude fiber. He notes apparent gains in crude fiber in two out of three cases and losses of from 0 per cent to 0.77 per cent in the crude protein present at ensiling. He bases his calculations on the assumption that there is no loss of ash during ensiling.

Several years later, at the Pennsylvania Experiment Station, Armsby and Caldwell (4), in connection with a comparative feeding experiment, using silage and dry corn fodder, found a loss of 10.76 per cent of the total dry matter ensiled. Their tables show a large loss in the ash and in the albuminoids, a small loss in crude fiber, and a large loss in the nitrogen-free extract, with a large gain in nonalbuminoids and in the crude fat.

Henry and Woll (5), at the Wisconsin Experiment Station, studied the losses in ensiling green corn by using three different varieties of corn in three square, wooden bay silos, holding from $8\frac{1}{2}$ to 12 tons each. They report 22 and 24 per cent losses of the total dry matter ensiled in two of the silos and 31.8 per cent loss in the remaining one, which broke and let in air. They find the largest losses to be in nitrogen-free extract, crude protein, and crude fiber. There was a large gain in ether extract in two of the silos. They also find a small gain of ash in one silo with a large loss in the others, which is explained as a translocation of the mineral matter caused by pressure of the upper layers on the lower ones, by movement of the juices of green fodder or by diffusion.

Woll (6), in another paper, gives additional data on silage studies taken up at the Wisconsin station. His summary of results for three silos indicates that he found a 37.15 per cent loss in albuminoid nitrogen and a 46.7 per cent gain in amido nitrogen during ensiling.

Short (7), in 1888, at the Wisconsin station finds during the ensiling of maize in three silos an average loss of 15.94 per cent of the dry matter and 21.26 per cent of the crude protein ensiled.

Woll (8), summarizing three years' work, including 10 experiments in which the comparative losses in ensiling and field-curing green maize were studied, reports that by ensiling there was a loss in the total dry matter of 20.5 per cent and in the crude protein of the green corn a loss of 20.6 per cent. He used silos holding 8 to 12 tons of silage.

In the fall of 1890, Woll (9) continued his experiments on the comparative losses in ensiling and field-curing green corn. He states in the report for the year ended June 30, 1891, that with a large rectangular silo of 80 tons' capacity, he found in the 65 tons of maize ensiled a loss of only 10.3 per cent in the total dry matter, and of 12.5 per cent in the crude protein. He attributes the larger losses of previous years to the smaller quantities of maize ensiled.

F. H. King (10), of the Wisconsin Experiment Station, in connection with his experiments to determine the necessary loss of dry matter in maize silage, studied the losses of total green material and total dry matter. Including all material taken out, whether good or spoiled, he finds in one year, in approximately 65 tons of maize ensiled, a loss of 7.35 per cent of the green matter and 4.95 per cent loss of the total dry matter. In the next year he finds a 5.78 per cent loss of green matter and 9.38 per cent loss of the total dry matter. He concludes that the loss may vary with the maturity of the maize at the time of ensiling.

Cooke (11), in the earliest investigations with maize silage reported from the Vermont Experiment Station, describes an investigation with an experimental round stave silo holding about 350 pounds of corn, covered by a follower under a pressure of 50 pounds per square foot. He states that the corn was cut while in the glaze and the silage was in perfect condition when taken out. His tables indicate a loss of 14.67 per cent of total dry matter; a loss in albuminoids, crude fiber, and nitrogen-free extract; and a gain in the fat of the maize ensiled.

Cooke and Hills (12), in a comparative study of the losses in maize silage and maize fodder, using a square wooden silo holding 12 tons, find a loss during ensiling of 20 per cent of the total dry matter, 13 per cent of the albuminoids, and 31 per cent of the sugars and starch in the maize ensiled.

The following year, in a somewhat similar experiment, the same authors (13) find a loss of 18 per cent of the dry matter, 11 per cent of the albuminoids, and 26.5 per cent of the sugars and starch of the green maize during ensiling.

Two years later Hills (14) reports a repetition of the investigation of the comparative losses in maize silage and maize fodder and gives a more detailed chemical report. He states that he found losses in the total amounts of the different constituents of the maize from harvesting to feeding to be as follows: Dry matter, 20 per cent; crude protein, 12 per cent; crude fiber, 5 per cent; nitrogen-free extract, 30 per cent; ether extract, 16 per cent; and a gain of 3 per cent in crude ash.

The director of the New York Experiment Station (15) at Geneva reports investigations extending over a period of three years, during which nine bags of green maize and seven bags of green sorghum were buried in a silo 14 by 15 by 30 feet. The bags weighed 50 pounds each at ensiling and, except for one bag of sorghum, were buried in sets of three, one bag at the center and the other two within a foot of opposite walls of the silo. The combined results of the 16 bags show during ensiling the following changes, which are based on the total amounts of each constituent of the maize ensiled: Losses—water, 3.9 per cent; ash, 0.4 per cent; albuminoids, 18.5 per cent; crude fiber, 9.8 per cent; nitrogen-free extract, 15.1 per cent; albuminoid nitrogen, 18.7 per cent; sugars and starch, 26.6 per cent; and dry matter, 12.6 per cent; grains—crude fat, 45.4 per cent; and amide nitrogen, 3.7 per cent.

Clements and Russell (16) state that they ensiled green maize in a round silo 12 feet in diameter and 17 feet high and examined the silage a few days and also three weeks after ensiling. Their tables show a loss in protein nitrogen and a gain in amide nitrogen, also a slight gain in fiber and in furfural, and they seem to indicate no trace of sugars remaining even after a few days' ensiling.

Russell (17) gives a summary of the investigations undertaken with maize silage over a period of five years at the South-Eastern Agricultural College, Wye, England. He concludes that the characteristic silage changes are the disappearing of sugar, of some of the less resistant cellulose, and of a part of the protein.

Annett and Russell (18), in a very interesting paper published in the *Journal of Agricultural Science* in 1908, give a discussion of various phases of silage investigation undertaken at the South-Eastern Agricultural College, Wye, England. They discuss quite thoroughly the losses and changes in the silo. Each year the investigators buried in a 12 by 17 foot round stave silo several sacks of from 10 to 15 kilos of fine-cut corn at different depths, and analyzed the maize when put in and when taken out of the silo.

The maize was cut green. In some seasons the dry matter was as high as 20 per cent and in cold, wet seasons as low as 13 per cent. They find practically no loss in crude fiber, but a very great loss in nitrogen-free extract, from which the sugar is shown by direct test to disappear almost entirely. The pentosans and protein suffer considerably. They state that the bags in the top half of the silo lost an average of 32 per cent of their original content of ether extract and 17 per cent of their soluble ash constituents, while the bags in the lower half gained over the original amounts 6 per cent in ether extract and 2 per cent in soluble ash constituents. They make note of a downward wash of soluble acids and ash. In a table stating an average of all losses and gains in original constituents present in the green material during the ensiling of maize during the seasons of 1904 and 1905, they give the losses as follows: Dry matter 36 per cent; ether extract, 16 per cent; nitrogen-free extract, 55 per cent; fiber, 8 per cent; total nitrogen, 26 per cent; protein nitrogen, 55 per cent; ash, 14 per cent; furfural, 32 per cent; and gains, non-protein nitrogen, 83 per cent.

Feruglio and Mayer (19) claim to find a loss of only 5 per cent in the food material during the ensiling of maize. They state that this loss falls somewhat on the pure protein and albuminoids, but most strongly on the sugars and pentosans. On the other hand, they find an increase in ether extract and total acidity.

THE EXPERIMENTAL WORK.

The silo used was a cylindrical concrete silo 42 feet high by 14 feet in diameter inside, holding approximately 150 tons, and located at the Dairy Division Experiment Farm, Beltsville, Md. The floor of the silo was 4 feet below the lowest door, and the silo up to this door was water-tight. The work was carried on for two seasons, 1914-15 and 1915-16. During both seasons the silo used was completely filled with corn. The depth of the silage after settling was approximately 38 feet.

MANNER OF PLACING AND REMOVING SAMPLES.

Samples of silage in cheesecloth sacks were buried at various depths and positions in the silo. The silo was divided into 8 levels the first season and 6 levels the second season. The first level was near the bottom of the silo and the last one near the top. The distance between levels was approximately the same. When a level was reached in the regular course of filling the silo a sack of the carefully sampled cut corn was weighed and buried at about the center. At the same time another sample was taken for chemical analysis. The sacks were numbered according to the level at which they were buried.

During the fall and winter the silage was fed out as usual, and whenever a level was reached the sack was removed, placed in a closed can, and immediately sent to the laboratory for analysis.

COLLECTION OF THE JUICE.

The floor of the silo was tapped and a 1-inch pipe conducted the silage juices to a receptacle outside and below the floor level of the silo. During the first season a barrel was used to receive the juice, but this proved unsatisfactory, and during the second season a covered concrete tank was employed. At first daily, later at more extended periods, the juice collected since the previous sampling was thoroughly mixed, and the sample, in an 8-ounce bottle, was immediately sent to the laboratory for analysis.

During the collection of a number of juice samples in the season of 1914-15 hard rains occurred which caused the barrel in which the juice was collected to overflow or diluted its contents, thus destroying the value of the respective samples. Owing to these facts, the results of this season's work on the juice are of value only as preliminary and as indicating the approximate amount of juice lost from the silo and the nitrogen contained therein.

METHOD OF ANALYZING SAMPLES.

The bags of silage were taken to the laboratory immediately after removal from the silo. After the weights were taken the contents were mixed and a 1-kilogram charge was taken for the gross-moisture determination. The remainder was pulped in a power meat grinder. The pulp was thoroughly mixed and charges for the various nitrogen determinations immediately taken. The charge for the gross-moisture determination was placed in a steam drying closet and dried at a temperature between 50° and 60° C. to a constant weight. It was then exposed to the air for several days and the final weight taken to represent the air-dry condition. The material was then ground in a power mill to a fine flour suitable for analysis.

The amino nitrogen was determined by the method of Van Slyke and the ammonia nitrogen by the method of Folin and Macallum. The other determinations were made according to the methods of the Association of Official Agricultural Chemists.

RESULTS OF THE ANALYSES.

The results of the experimental work are given in the following tables. Table 1 gives the weight and chemical composition of the corn in each sack as it was buried. Table 2 shows the weights and chemical composition of the contents of the sacks as they were re-

moved from the silo. Table 3 was calculated from the preceding tables and shows the losses or gains in each sack based on the weights ensiled. Tables 4 and 5 give the weights and chemical analyses of the juice.

TABLE 1.—*Summary of analyses of cut corn as placed in bags.*

SEASON 1914-15.

Bag No.	Weight.	Moisture.	Total nitrogen.	Albuminoid nitrogen.	Ether extract.	Crude fiber.	Ash.	Total sugar.	Nonreducing sugar.	Furfural.
	<i>Grams.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
1.....	3,350	68.54	0.451	0.334	0.52	6.15	1.33	4.23	0.39	3.64
2.....	7,740	67.18	.406	.344	.58	6.29	1.02	3.93	1.83	3.71
3.....	5,510	67.21	.406	.418	.63	5.65	1.18	4.16	1.03	4.74
4.....	6,220	66.23	.434	.347	.64	6.17	1.18	3.07	1.30	3.74
5.....	6,390	69.13	.45	.362	.54	5.89	1.53	3.67	0.71	3.49
6.....	6,640	74.60	.329	.282	.42	4.55	1.02	3.30	0.09	2.72
7.....	6,620	69.90	.394	.349	.58	6.17	1.56	2.64	0.68	3.37
8.....	5,870	72.19	.370	.286	.47	5.92	1.38	2.46	0.72	3.30
Average.....		69.39	.413	.340	.55	5.84	1.31	3.39	1.28	3.56

SEASON 1915-16.

1.....	5,615	76.95	0.398	0.326	.....	.....	1.29	2.97	0.51	2.33
2.....	4,685	72.02	.434	.339	.....	.....	1.91	3.57	.68	3.03
3.....	7,170	76.63	.360	.307	.....	.....	1.49	2.98	.17	2.47
4.....	7,180	75.18	.374	.317	.....	.....	1.31	3.17	.29	2.55
5.....	7,935	74.80	.416	.325	.....	.....	1.13	3.23	.28	2.70
6.....	7,540	73.28	.344	.320	.....	.....	1.57	3.03	.79	2.75
Average.....		74.89	.385	.321	.....	.....	1.42	3.14	.46	2.63

TABLE 2.—*Summary of analyses of silage as removed from bags.*

SEASON 1914-15.

Bag No.	Weight.	Gain (+) or loss (-).	Moisture.	Total nitrogen.	Albuminoid nitrogen.	Ether extract.	Crude fiber.	Ash.	Total sugar.	Nonreducing sugar.	Furfural.	Amino nitrogen.	Ammonia nitrogen.
	<i>Grams.</i>	<i>Grams.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Parts per million.</i>	<i>Parts per million.</i>
1...	3,800	+250	75.14	0.442	0.154	0.65	5.10	1.22	0.12	None.	2.68	1,530	302
2...	8,550	+810	71.02	.427	.168	.59	5.58	1.14	.08	None.	3.24	1,420	264
3...	6,400	+890	73.36	.491	.237	.78	4.91	1.13	.13	None.	2.69	1,510	304
4...	7,920	+1,700	74.48	.405	.155	.70	4.69	1.16	.15	None.	2.62	1,360	278
5...	7,070	+790	77.30	.396	.149	.67	4.40	1.20	.09	None.	2.33	1,440	246
6...	6,355	-245	75.32	.349	.106	.64	4.51	1.13	.74	None.	2.44	1,250	257
7...	7,655	+1,035	76.83	.331	.110	.70	4.94	1.27	.00	None.	2.45	1,890	305
8...	6,560	+690	78.52	.312	.114	.45	4.74	1.25	.17	None.	2.49	1,900	105
Average.....			75.15	.392	.149	.65	4.87	1.19	.18	.....	2.63	1,538.8	257.6

SEASON 1915-16.

1...	5,510	-105	78.80	0.382	0.139	.....	.....	1.31	0.09	None.	2.28	1,480	274
2...	5,170	+485	78.12	.392	.118	.....	.....	1.72	.08	None.	2.37	1,320	252
3...	6,210	-960	77.34	.354	.176	.....	.....	1.64	.09	None.	2.46	1,040	180
4...	6,870	-310	75.58	.379	.139	.....	.....	1.23	.40	None.	2.39	1,480	217
5...	7,775	-160	76.98	.386	.142	.....	.....	1.07	.35	None.	2.16	1,440	256
6...	7,350	-190	75.98	.322	.133	.....	.....	1.40	.11	None.	2.41	1,120	192
Average.....			77.02	.368	.142	.....	.....	1.37	.20	.....	2.31	1,313.3	228.5

TABLE 3.—*Summary of losses and gains, based on weights ensiled.*
SEASON 1914-15.

Bag No.	Green mat- ter.	Mois- ture.	Dry mat- ter.	Total nitro- gen.	Albu- min- oid nitro- gen.	Non- albu- minoid nitro- gen.	Ash.	Ether ex- tract.	Crude fiber.	Total sugar.	Fur- fural.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
1.....	+13.43	+24.36	-10.36	+11.16	-47.69	+179.18	+4.05	+41.79	-5.93	-96.75	-16.48
2.....	+10.47	+16.78	-2.46	+16.18	-46.04	+361.53	+23.45	+12.37	-2.00	-97.73	-3.53
3.....	+16.15	+26.78	-5.63	+12.71	-34.15	+235.31	+11.23	+43.82	+.94	-96.37	-34.07
4.....	+27.33	+43.17	-3.78	+18.82	-43.13	+265.94	+25.17	+39.26	-3.21	-93.76	-10.80
5.....	+10.64	+23.73	-18.64	-2.64	-54.47	+210.56	-27.45	+37.26	-17.35	-97.31	-26.13
6.....	-4.29	-3.37	-7.00	+1.52	-64.01	+394.75	+6.03	+45.82	-5.13	-78.54	-14.14
7.....	+15.63	+27.10	-10.99	-2.86	-63.55	+467.94	-5.86	+39.56	-7.42	-100.00	-15.93
8.....	+11.75	+21.55	-13.69	-5.76	-55.45	+163.41	+1.23	+6.99	-10.52	-92.31	-15.67
Average of 4 top bags ¹	+8.31	+16.71	-12.74	-2.46	-59.41	+277.24	-8.96	+33.31	-10.29	-91.65	-18.24
Average of 4 bottom bags ¹	+16.87	+27.43	-4.70	+15.19	-42.18	+264.33	+17.61	+31.92	-2.26	-96.35	-15.60
Average of all bags...	+12.35	+21.61	-8.66	+6.49	-50.76	+270.36	+2.07	+32.59	-6.34	-94.14	-17.07

SEASON 1915-16.

1.....	-1.87	+0.49	-9.75	-5.82	-58.16	+231.16	-0.35	.....	.....	-97.00	-3.98
2.....	+10.35	+19.70	-13.71	-.33	-61.59	+136.96	-.63	.....	.....	-97.49	-13.68
3.....	-13.39	-12.59	-16.01	-14.84	-50.34	+190.90	-4.67	.....	.....	-97.37	-13.73
4.....	-4.32	-3.81	-5.86	-3.04	-58.04	+302.96	-10.16	.....	.....	-87.91	-10.32
5.....	-2.02	+.84	-10.49	-9.08	-57.19	+162.72	-7.22	.....	.....	-89.38	-21.62
6.....	-2.52	+1.07	-12.37	-8.75	-59.47	+667.40	-13.07	.....	.....	-96.45	-14.57
Average of 3 top bags ¹	-2.91	-.57	-9.72	-7.09	-58.21	+276.14	-10.43	.....	.....	-91.18	-15.78
Average of 3 bottom bags ¹	-3.32	-.04	-13.41	-7.59	-56.08	+184.70	-2.16	.....	.....	-97.32	-10.88
Average of all bags...	-3.09	-.34	-11.29	-7.31	-57.27	+231.79	-6.54	.....	.....	-93.90	-13.68

¹ These averages are based on weights obtained rather than on the percentages of the different com-
pounds in each bag as shown in this table.

TABLE 4.—*Summary of analyses of juice; season 1914-15.*

Sample No.	Weight.	Specific gravity.	Acidity ¹	Total ni- trogen.	Albumi- noid ni- trogen.	Nonalbu- minoid nitrogen.	Total ni- trogen calcu- lated as protein.
	<i>Pounds.</i>		<i>C. c.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Pounds.</i>
1.....	57	1.008	0.59	0.0432	0.0176	0.0256	0.1539
2.....	81	1.022	17.29	.138	.....	.....	.6966
3.....	84	1.030	24.54	.190	.....	.....	.9997
4.....	126	1.034	29.12	.234	.0211	.2129	1.834
5.....	127	1.036	30.80	.232	.....	.....	1.842
6.....	128	1.039	32.70	.254	.....	.....	2.035
7.....	108	1.040	32.66	.269	.....	.....	1.814
8.....	94.75	1.040	33.14	.278	.0314	.2466	1.700
9.....	61	1.040	33.64	.283	.0295	.2535	1.080
10.....	52.5	1.040	32.45	.290	.0295	.2605	.9399
11.....	29.25	1.041	33.85	.291	.0259	.2651	.6323
12.....	59	1.042	33.83	.296	.0259	.2701	1.091
13.....	58.25	1.042	33.08	.288	.0281	.2599	1.048
14.....	28.25	1.042	32.83	.292	.0251	.2669	.617
15.....	25	1.042	32.83	.297	.0258	.2792	.465
16.....	28.5	1.041	29.69	.282	.0226	.2594	.502
17.....	14.25	1.046	32.95	.320	.0306	.2894	.295
18.....	18	1.047	32.45	.328	.0306	.2974	.369
19.....	151.75	1.018	16.17	.126	.0131	.1129	1.200
20.....	131	1.022	20.14	.163	.0176	.1454	1.336
21.....	50.0	1.026	23.06	.187	.0178	.1692	.585
22.....	38.5	1.028	24.03	.202	.0168	.1852	.485
23.....	31.5	1.029	24.50	.208	.0191	.1889	.410
24.....	42.5	1.029	25.45	.214	.0202	.1938	.570
25.....	22.5	1.031	26.88	.230	.019	.211	.324
26.....	73.25	1.022	21.14	.174	.017	.151	.7984
27.....	176.25	1.013	13.31	.099	.013	.086	1.0928
28.....	77.25	1.009	8.83	.075	.006	.069	.3631
29.....	36.50	1.026	26.11	.195	.015	.180	.4453
30.....	140.00	1.014	12.53	.109	.010	.099	.9520
31.....	31.00	1.034	30.99	.269	.022	.247	.5208
32.....	127.00	1.008	7.82	.060	.005	.055	.4826
33.....	149.25	1.015	15.03	.119	.007	.112	1.1045
34.....	90.00	1.023	23.12	.195	.012	.183	1.098
35.....	8.00	1.026	19.83	.187	.015	.172	.0936
36.....	23.00	1.009	7.06	.064	.005	.059	.0920

¹ The figures in this column represent the number of cubic centimeters of normal alkali required to neu-
tralize the acid in 100 grams of the juice.

Total weight of juice, 2,579 pounds. Total weight of nitrogen calculated as protein, 28.88 pounds.

TABLE 5.—*Summary of analyses of juice; season 1915-16.*

Sample No.	Number of days represented.	Weight.	Specific gravity.	Acidity. ¹	Total nitrogen.	Albuminoid nitrogen.	Ammonia nitrogen.	Amino nitrogen.	Total nitrogen calculated as protein.
		<i>Pounds.</i>		<i>C. c.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Parts per million.</i>	<i>Parts per million.</i>	<i>Pounds.</i>
1.....	1	40	1.027	22.8	0.139	0.0384	174.2	710.1	0.3480
2.....	1	81	1.029	24.4	.168	.0384	183.1	850.9	.8505
3.....	1	142.5	1.030	21.4	.184	.0384	171.7	854.5	1.6388
4.....	1	166	1.029		.195				2.0252
5.....	1	498.5	1.029	21.4	.208	.0352	193.7	1,073	6.4805
6.....	1	655.5	1.029	21.4	.211	.0368	190.4	1,073	8.6526
7.....	2	1,046	1.029	21.4	.227	.0320	205.4	1,133	14.8532
8.....	1	650	1.030	29.0	.240	.0400	215.7	1,119	9.7500
9.....	1	413	1.030	29.0	.245	.0496	224.6	1,159	6.3189
10.....	1	290.7	1.030	28.5	.246	.0304	229.2	1,203	4.4775
11.....	1	237.5	1.030	29.0	.245	.0416	240.3	1,220	3.6338
12.....	1	169.5	1.030	28.5	.254	.0400	232.4	1,214	2.6951
13.....	2	313	1.030	28.1	.251	.0464	233.4	1,240	4.9141
14.....	1	160	1.030	28.3	.250	.0368	243.0	1,246	2.4960
15.....	2	250	1.0295	28.3	.258	.0464	248.5	1,317	4.0250
16.....	3	429	1.029	27.2	.251	.0464	249.8	1,285	6.7353
17.....	5	424	1.030	28.0	.258	.0336	255.1	1,263	6.8264
18.....	4	262.5	1.030	29.7	.266	.0384	295.6	1,392	4.3575
19.....	5	340	1.030	30.5	.262	.0352	301.7	1,401	5.6580
20.....	3	172.3	1.030	31.8	.251	.0432	309.6	1,462	2.7033
21.....	6	257	1.032	34.1	.277	.0384	316.8	1,498	4.4461
22.....	2	147	1.032	34.6	.262	.0384	317.9	1,503	2.4108
23.....	6	254	1.035	36.3	.291	.0336	334.7	1,539	4.6228
24.....	4	171.5	1.034	36.8	.290	.0384	332.4	1,517	3.1042
25.....	7	205	1.035	36.8	.280	.0144	329.4	1,558	3.5875
26.....	4	107	1.035	37.0	.285	.0128	356.3	1,663	1.9046
27.....	4	107	1.036	37.5	.288	.01536	374.4	1,717	1.9260
28.....	3	106	1.036	37.8	.290	.0144	371.2	1,757	1.9186
29.....	8	177	1.040	38.6	.298	.0160	387.7	1,771	3.2922
30.....	8	115	1.040	39.5	.302	.0144	394.5	1,762	2.1735
31.....	12	124	1.040	39.3	.306	.0144	438.3	1,959	2.3684
32.....	9	89	1.040	38.6	.304	.0112	416.0	1,941	3.5910
33.....	8	68	1.042	38.5	.315	.0118	429.5	1,986	1.3396
34.....	9	65	1.046	39.3	.320	.01328	441.6	2,139	1.3000
35.....	13	89	1.041	35.3	.299	.01200	415.4	1,979	1.0643
36.....	10	58	1.045	36.2	.315	.01280	416.4	1,972	1.1426
37.....	20	90	1.045	34.1	.322	.0182	429.6	1,962	1.8090
38.....	22	880	1.045	32.0	.323	.0211	448.7	1,962	1.6160
39.....	14	49	1.042	28.2	.299	.0216	416.8	1,967	.9163
40.....	15	51	1.039	26.7	.274	.0151	397.1	1,637	1.8721
41.....	21	64.5	1.040	24.2	.275	.0189	395.9	1,759	1.1094
42.....	30	122	1.037	28.3	.267	.0195	419.8	1,505	2.0374
43.....	34	157.5	1.030	26.6	.219	.0158	369.3	1,318	2.1578
Average.....			1.0345	31.17	.263	.0283	317.9	1,472.9	

¹ The figures in this column represent the number of cubic centimeters of normal alkali required to neutralize the acids in 100 grams of the juice.

Total weight of juice, 9,494.5 pounds. Total weight of nitrogen calculated as protein, 150.75 pounds.

DISCUSSION OF RESULTS.

The investigation was conducted under all the difficulties inherent in practical farm conditions. The silo was not in any sense an experimental silo. The burial and removal of the bags took place during the regular course of filling the silo and feeding out the silage. In the season of 1914-15 the filling extended over a period of 17 days and the feeding out took nearly 3 months from the first bag to the last. In the season of 1915-16 the filling took only 8 days but the feeding out extended over a period of nearly 7 months. In the former season the corn was considered somewhat overmature and for a few minutes during each day's run water was added through the distributor. In the latter season the corn was considered less mature than is desirable for the best quality of silage.

TEMPERATURE AND COLOR CHANGES.

The changes that occur in corn during fermentation in the silo have been the subject of much study by numerous investigators, both in this country and in Europe. First, there is a more or less rapid rise in temperature of the silage mass, the degree of which depends somewhat upon the temperature of the outside air and more perhaps upon the state of maturity of the corn and the degree of fineness to which it is cut. This is followed by a gradual decline in temperature of the silage and a change of color from the green of the fresh-cut corn to a greenish-brown. These changes in physical appearance are accompanied by a copious evolution of carbon dioxide and the formation of volatile and nonvolatile acids, which have been shown to consist largely of acetic and lactic acids. The sugars both of the reducing and nonreducing type which are present in green corn disappear almost completely during the fermentation process. A large part of the albuminoid nitrogen disappears, and there is a great increase in the amount of nonprotein nitrogen, some of which appears as amino acids.

The causes which produce these profound changes have been the subject of considerable dispute, some writers taking the ground that bacterial action is entirely responsible, others that bacteria have little if anything to do with them, and still others contend that the changes are due in part to bacterial and in part to enzymatic action.

DOWNWASH OF SOLUBLE MATERIAL.

The results of the chemical analyses as given in the tables show many evidences of a downwash of soluble material, the upper part of the silo losing and the lower part gaining. In 1914-15 about 2,600 pounds of juice were collected, and in 1915-16 about 10,000 pounds. Doubtless had this juice not been allowed to escape, the analytical results for the bags in the lower part of the silo would have shown a greater loading up with soluble constituents, or at least smaller losses. Especially is it believed that this would have been true in 1915-16 when the loss in juice rose to almost 5 tons. A difficulty in controlling conditions is the impossibility of removing the bags simultaneously so that they would all have been in the silo the same length of time. This factor might be quite important in the 1915-16 work, when from 1 to nearly 3 months elapsed between the recovery of several of the bags.

The tables showing losses and gains of green matter and of moisture during ensiling show by comparison the marked effect of adding water when filling the silo. Indeed, the tendency of certain soluble constituents to wash downward in the silo, which was probably obscured the second season by the excessive outflow of juice, may have been

enhanced the first season by the addition of water to the corn at ensiling.

In the season of 1914-15 the change in amount of green matter varies from a loss of 4.29 per cent in the weight of bag No. 6 to a gain of 27.33 per cent in the weight of bag No. 4. The average gain for all bags is 12.35 per cent. The gain for the bags in the upper half averages 8.31 per cent and for the lower half, 16.87 per cent. That the apparent gain in green matter is only a gain in water which more than offsets any loss in dry matter is shown by a comparison, bag by bag, of the figures for gain in green matter and moisture.

In the season of 1915-16, when the corn was somewhat immature and no water was added while filling the silo, there is a loss in green matter in 5 of the 6 bags. The average loss is 3.09 per cent per bag, and the slightly greater loss in the lower than in the upper half probably is due to the large loss of juice that took place. The change in the amount of moisture present, less than 1 per cent, is comparatively unimportant, though it should be noted that the 2 lower bags register gains.

LOSS OF DRY MATTER.

The greatest loss in dry matter in any bag in 1914-15 is but 18.64 per cent, while the average loss for all the bags is 8.66 per cent. The apparent downwash of the soluble dry matter is illustrated very well that season by a comparison of the losses. The bags in the upper and lower halves show, respectively, 12.74 per cent and 4.70 per cent losses in dry matter.

In the season of 1915-16 the figures do not, on their face, bear out this transfusion, there being an increase in loss from 9.72 per cent in the upper half to 13.71 per cent in the lower half. This apparent reversal of the results of the previous season may be and probably is due to the very much larger outflow of juice. The loss in any individual bag does not run as high as in the previous season, but the average percentage loss of dry matter as ensiled is nearly 3 per cent more, being 11.29 per cent.

TOTAL NITROGEN.

The figures for total nitrogen in 1914-15 show a gain in 5 out of 8 bags, while in 1915-16 they show a loss in every bag. The figures for the first season show very plainly that there must have been a downwash of nitrogenous material, for while there is a loss of 2.46 per cent in the bags from the top half of the silo, there is a gain of 15.19 per cent over the total nitrogen ensiled in the bags representing the lower half. The fact that this gain in the lower bags raises the average total nitrogen in all the bags may be accounted for by irregularities in the downwash by which more nitrogenous material was washed into the lower bags than was washed out of the upper ones.

In 1915-16 the average figures for total nitrogen show a loss of 7.31 per cent, with almost exactly the same losses for the upper and lower bags. If it were not for the unaccountably high loss of nitrogen in bag No. 3, the losses for the bags in the lower half would be less than those in the upper half. However, even considering the figure for bag No. 3 as normal, the large loss of nitrogen in the juice would supply a reason why the average figures for total nitrogen show no differences between the bottom and top halves of the silo. The average losses in total nitrogen in all bags for both seasons are very moderate when compared with the results of other investigators.

The smallest loss in albuminoid nitrogen for either season is 34.15 per cent, the largest 64.01 per cent, which also occurs in the same season. The average total loss for 1914-15 is 50.76 per cent and for 1915-16 57.27 per cent. The slightly greater loss in albuminoid nitrogen in the latter season may or may not be due to the less mature condition of the corn when ensiled.

The nonalbuminoid nitrogen is, of course, very small in amount in the corn when ensiled, but increases several times its own weight during ensiling in both seasons. The increase is 270.36 per cent the first season and 231.79 per cent the second season.

ASH.

The figures for loss or gain in ash for both seasons show very plainly the transfusion from the upper half to the lower half of the silo. In 1914-15, 2 of the 4 upper bags gained slightly and the other 2 lost strongly, while all 4 bottom bags gained strongly and consistently. The average for the top bags shows a loss of 8.96 per cent and for the bottom bags a gain of 17.61 per cent. The total average gain of 2.07 per cent may be explained in the same way as the gain in total nitrogen. The figures for 1915-16, while showing losses throughout, show plainly that less ash is lost from the bottom bags than from the top bags. The loss for the top bags was 10.43 per cent and for the bottom bags only 2.16 per cent, which latter would probably have been a gain had no juice escaped.

SUGARS.

The sugars, as has been shown by previous investigators, are the source of much of the actual weight loss of dry matter during ensiling. In both years the nonreducing sugars entirely disappeared and only about 6 per cent of the reducing sugars was left. The loss is slightly greater in the lower bags than in the upper. This is probably due to the fact that fermentation has had a longer time to act on the sugars that remain after the first period of rapid action has taken place.

FURFUROL.

The furfural-yielding bodies show a loss in both seasons, in 1914-15, 17.07 per cent; in 1915-16, 13.68 per cent. Like the albuminoids they show a smaller loss in the lower than in the upper bags.

ETHER EXTRACT AND CRUDE FIBER.

The ether extract and crude fiber were determined only for the season 1914-15. The former shows an average gain for all bags of 32.59 per cent, this gain being slightly greater in the upper four bags than in the lower four. This consistent increase, which is quite in harmony with the results of previous investigators, is, no doubt, due to the formation of new ether-soluble bodies during the fermentation process.

The crude fiber shows an average loss of 6.34 per cent of its weight at ensiling. Like the albuminoids and furfural it shows a smaller loss in the lower than in the upper bags. The lower bags lost an average of 2.26 per cent, while the upper bags lost an average of 10.29 per cent.

COLLECTION AND ANALYSIS OF JUICE.

The total amount of juice collected during the season of 1914-15 was only about one-quarter as much as that collected in the following season. This is doubtless attributable to the condition of the corn at ensiling, which in the former season had become so mature that water had to be added, and in the latter season was rather too immature.

An inspection of the table giving the analyses of the juice for 1915-16 shows that the amount of the solids, as indicated by the specific gravity, the acidity, and the nonalbuminoid nitrogen, seems to follow the same general curve. There appears to be a gradual rise during the first part of the period of juice collection, followed by a gradual fall. The only exception seems to be the albuminoid nitrogen, which, while showing a slight tendency to follow the specific gravity curve, in amount shows a gradual but continuous decrease from the first sample taken to the last. In percentage it decreases from over one-fourth of the total nitrogen to less than one-nineteenth.

AMMONIA NITROGEN AND AMINO NITROGEN.

In the season of 1914-15 the bags contained an average of 257 parts per million of ammonia nitrogen and 1,540 parts per million of amino nitrogen. In the season of 1915-16 the bags contained an average of 228 parts per million of ammonia nitrogen and 1,313 parts per million of amino nitrogen. By calculation it is found that in both seasons the ratio of ammonia nitrogen to amino nitrogen is slightly greater in the bags in the lower half than in those in the

upper half of the silo. This is only what would be expected when it is considered that the ammonia nitrogen is a decomposition product of the amino bodies and the longer stay in the silo gives more time for such decomposition to take place.

The amounts of amino and of ammonia nitrogen, expressed in parts per million, do not follow parallel curves, although there is a general rise and fall throughout the whole period of juice collection. The proportionate increase in the amount of amino nitrogen is greater, as is also the later decrease. The ammonia nitrogen in the first sample is nearly one-fourth as much as the amino nitrogen, but as the amount of amino nitrogen increases much more rapidly than the ammonia nitrogen it drops in the fifth sample to less than one-fifth. The proportion remains at one-fifth, or below, up to the sixteenth sample and then slightly rises to the thirty-sixth sample. Here the amount of ammonia nitrogen decreases slowly and the amount of amino nitrogen decreases rapidly; consequently, the proportion of ammonia nitrogen to amino nitrogen in the last two samples is raised to over one-fourth.

The specific gravity ranges from 1.027 to 1.046 and the acidity from an amount requiring 21.4 cubic centimeters to an amount requiring 39.5 cubic centimeters normal alkali for 100 grams of juice. The total nitrogen varies from 0.139 per cent to 0.323 per cent, and the albuminoid nitrogen from 0.0112 per cent to 0.0496 per cent.

The ammonia nitrogen ranges from 171.7 to 448.7 parts per million and the amino nitrogen from 710 to 2,139 parts per million.

It will be seen from the tables that the greater part of the nitrogen present in the juice escaping from the silo is in the form of soluble nonalbuminoid nitrogen compounds. Although the actual food value of such compounds is still somewhat a matter of controversy, yet it may be a matter of interest, from a practical standpoint, to observe the possible loss of food material caused by the escape of juice these two years. If the total nitrogen of the 2,579 pounds of juice collected in 1914-15 is expressed as pure protein, we have a loss of 28.89 pounds, which represents the protein in about 1,500 pounds of average silage. Expressing in the same way the results for the season of 1915-16, we have a loss of 150.75 pounds in the 9,494.5 pounds of juice collected, representing the protein in about 7,500 pounds of average silage.

On a technical basis the results of the two seasons' study of silage juice may furnish some explanation for the large variations in the losses of soluble silage constituents which are occasionally reported by investigators. It shows how a large amount of juice, carrying with it much soluble food material, may sink to the bottom of the silo or easily be lost through cracks or through an earthen floor.

CONCLUSIONS.

The two years' work furnishes evidence of a downwash of the juice in the silo, carrying with it soluble-food materials, so that the silage in the lower part of the silo may gain in food material at the expense of the upper part.

There was an average loss for all the bags of nearly 10 per cent of the dry matter, which apparently is due largely to the fermentation of the carbohydrates and to the carrying away of soluble material by the juice. The reducing and nonreducing sugars almost entirely disappeared. There was a considerable loss in crude fiber and in the fufurol-yielding bodies.

There was a loss in total nitrogen. It is probable, however, that this loss is due largely, if not entirely, to the nitrogenous compounds which escaped in the juice. The albuminoid nitrogen suffered a loss of over 50 per cent, while the nonalbuminoid forms increased several times their own weight.

There was a gain in ether extract, which is probably due to the formation of new ether-soluble bodies.

The juice which was collected the second season amounted to nearly 10,000 pounds. This juice averaged 0.263 per cent total nitrogen, 0.0283 per cent albuminoid nitrogen, and 317.9 parts ammonia nitrogen and 1,472.9 parts amino nitrogen per million.

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BULLETIN No. 954

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JOHN R. MOHLER, Chief



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WINTERING AND SUMMER FATTENING OF STEERS IN NORTH CAROLINA.

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OUTLINE OF THE EXPERIMENTAL WORK.

During the fall of 1913, the Bureau of Animal Industry, United States Department of Agriculture, in cooperation with the North Carolina Agricultural Experiment Station, began a series of beef-cattle experiments on the grazing farm of T. L. Gwyn, near Springdale, Haywood County, N. C. This is in the western part of the State where most of the cattle produced are for beef purposes.

This work has been in progress six years. The first three years' work, reported in United States Department of Agriculture Bulletin No. 628 and in North Carolina Department of Agriculture Bulletin No. 240, comprised the following: (a) Wintering steers both in barns and on pastures; (b) summer fattening of steers on pasture with and without cottonseed cake; and (c) winter fattening of beef cattle. During the second three years the winter fattening and the supplementing of grass with cottonseed cake for summer fattening were discontinued, because these practices were found not generally profitable under western North Carolina conditions. However, the use

¹ Mr. Farley, the senior author of this bulletin, resigned from the department in June, 1919.

of cottonseed cake to supplement summer pasture had been profitable the first two years, which was before the rapid rise in prices of feeds began. The three years' work here reported dealt with various phases of wintering and summer fattening of steers.

THE REGION AND ITS PROBLEMS.

Most of the land in western North Carolina and the surrounding territory, shaded on the map, figure 1, is extremely rough and mountainous and suited only for grazing. There are thousands of acres of cut-over timberland, recently left by lumbering operations, which are



FIG. 1.—Map showing location of experimental work (heavy black dot) and area (shaded) suitable for similar cattle-feeding operations; also local and principal cattle markets.

practically worthless in their present condition. In many of the mountainous counties only from 5 to 10 per cent of the land can be cultivated, and much of this is mountain and hillsides which should be in grass. The production of stocker and feeder cattle is especially practicable on account of the large areas available for pasture and the relatively small quantity of winter feed necessary for the maintenance and growth of such cattle. The fattening of cattle is much less practicable than the growing of cattle because of the greater quantity of feed necessary. Where feed has to be shipped in by rail, as is usually the case with the concentrates, the distance from the railroad station makes the fattening of cattle prohibitively costly for many farmers.

On account of the relatively small area of land which can be cultivated profitably, the chief problem with most of the cattlemen in this section, as in other range sections, is to keep as many cattle through the winter as can be grazed during the summer. The men who have good pastures suitable for fattening a carload or more of steers nearly always buy their stockers in the fall. They buy part of them from men who keep a large herd of cows to raise stockers, and the rest from small farmers who keep from one to six cows. Nearly all the cattle are roughed through the winter on very light rations. Relatively few are fed on silage. It is expected that they will lose weight rather heavily during the winter, but that they will put it back very cheaply on grass the following summer. They are sold as two-year-olds for feeding purposes, going principally to the blue-grass region of the Virginias and the feed lots of Pennsylvania.

OBJECTS AND PLAN OF THE WORK.

This work was undertaken to determine the following:

- 1.—The value of pastures in this section for wintering and finishing cattle.
- 2.—The effects of the different methods of wintering on the gains made on grass the following summer.
- 3.—A way by which stockmen can winter more cattle than is the case at present.
- 4.—The relative cost of various methods of keeping steers through the winter.

The work was planned to cover a period of three years to get averages practically free from the effects of variations in seasons, feed, pasture, and cattle. The feeds selected to determine the most economical winter ration were: Mixed hay, corn silage, corn silage with stover and straw, and winter pasture, that had not been grazed the preceding summer. The methods tested as to their possibilities for carrying more cattle through the winter were the use of silage and winter pasture. The steers used were divided into four lots for each of the first two years and five lots for the third year, there being about a carload of cattle in each lot. The lots were as nearly uniform in quality and condition as it was possible to make them. At the close of each of the three winter periods the cattle were carried through the summer on grass. The steers were numbered the same as in the previous winter's work so that the records of each lot of cattle could be followed from one fall until the next fall. As the steers were not given any other feed while they were on summer pasture, all gains can be credited to the pasture on an acreage basis. An outline of the work is given in Table 1. Changes in this general outline made necessary by the giving out of the supply of the various roughages at various times before the end of the winter periods are noted in Table 2.

TABLE 1.—*General plan of the three years' work.*

Lot No.	Season.	Steers in lot.	Winter feed. ¹	Summer feed. ²
1	1916-17	28	Mixed hay.....	Grass.
	1917-18	25	do.....	Do.
	1918-19	25	do.....	Do.
2	1916-17	25	Corn silage.....	Do.
	1917-18	25	do.....	Do.
	1918-19	25	do.....	Do.
3	1916-17	25	Corn silage, stover, and straw.....	Do.
	1917-18	30	do.....	Do.
	1918-19	30	do.....	Do.
4	1916-17	17	Winter pasture.....	Do.
	1917-18	40	do.....	Do.
	1918-19	25	do.....	Do.
5	1918-19	20	Stover, hay and straw.....	Do.

¹ From about Dec. 12 to Apr. 15.² From about Apr. 15 to Sept. 5, when they were sold as feeders.³ The plan was to winter-graze the steers of Lot 5 in 1918-19, but a shortage of winter pasture prevented it.

FIG. 2.—Character of experimental cattle and pasture land.

KIND OF STEERS USED.

The cattle used in this work were all western North Carolina-grown steers. They were mostly 2-year-olds, averaging about 800 pounds each when purchased in the fall. They were a good, uniform lot of grade cattle, representing Shorthorn blood principally, with some Angus, Hereford, and Devon intermixed.

FEEDS USED.

The winter feeds—corn silage, stover, corn, and straw—were such as are ordinarily produced on the farm. The hay consisted largely of a mixture of red clover, timothy, orchard grass, and redtop.

Most of the summer pastures had been established for some time. Some of them were winter pastures which had been used in the previous three years' work. These pastures consisted largely of a

mixture of blue grass, red clover, and orchard grass, with some timothy and redtop, or herd's grass, which is the common summer-pasture mixture used in this part of the State. Most of the land was unusually rolling, or exceedingly rough, with the deadened trees still standing.

WINTER PASTURES AND THEIR ESTABLISHMENT.

The winter pastures used in these experiments were cut-over timberland which had been seeded to grass after all the merchantable saw timber, chestnut wood, and acid and pulp wood were removed. Much of this land was covered with the tree tops left from lumbering and the natural undergrowth of bushes, and small trees.

One method extensively used for getting the land seeded to grass is to give some of the surrounding farmers free use of the land for two years for growing corn, provided they will deaden all the large trees and clear out the bushes and tree tops. The land is plowed very shallow and the rows of corn run around the hills to prevent washing. The average crop of corn so produced will range from 40 to 60 bushels per acre. The land is not suited, however, for continuous cropping because it is too inaccessible and cultivation is too expensive.

When the corn is cultivated the last time the second year, a grass mixture consisting of 15 pounds of orchard grass and 5 pounds of blue grass per acre is sown. This seed is furnished by the owner of the land and broadcasted through the corn. The grass will soon produce a firm sod, sufficient to prevent washing of the land. The orchard grass not only grows well on the steep mountain sides, but it comes on earlier in the spring and lasts to a later date in the fall than any other grass that can be used.

The method of cultivating the land in corn before seeding has proved very satisfactory, but it is becoming more difficult to lease the land in this way because of the shortage and high price of farm labor. A second method which has been used during the last three years and which has proved to be better in several respects is as follows:

In the spring, before the timber begins to leaf out, the tracts of land are burned over very thoroughly. If this is done at the right time, most of the tree tops will be completely burned and the undergrowth and some of the trees will be killed. After the ashes are cool, the grass mixture is sown by hand and the larger trees are deadened. The ashes soon cover the seed and the first rains beat them into the ground. The land is neither plowed nor harrowed. It has been found that the bushes, sprouts, and weeds which naturally spring up can be kept down best by turning on a few cattle soon after the grass comes up. This keeps the land clean and the packing helps to make a better sod.

The land should not be pastured heavily the first summer, as this will injure the pasture materially for winter-pasture purposes. Land so seeded and handled makes a good pasture for the first winter.

By this method much larger areas can be seeded at one time. If the land is cultivated, it not only delays seeding but also limits the amount which can be put in pasture each year, and also when the grass is seeded in the corn it is necessary to let it grow one year before it can be used at all.

All undergrowth and sprouts must be kept down regardless of the method of seeding that is used. If the method of seeding in the corn is followed it is not difficult to keep the undergrowth down provided the land is gone over at the proper time. These pastures should not



FIG. 3.—The type of steers, and some of the rough land in the experimental work.

be used for winter pasture for more than two years in succession, after which they should be alternated and used as summer pasture.

The seed is the greatest expense in getting the land in grass. Burning the land over and the actual sowing of the seed are very small items. Considering the fact that a crop of corn is raised for two years when the first method of seeding is used, there is very little difference in the cost of the pasture. Either one of these plans can be followed throughout the mountainous sections of the State.

METHOD OF FEEDING AND HANDLING THE STEERS.

All the cattle in Lots 1, 2, and 3 each year, and in Lot 5 in 1918-19, were wintered in a barn. They were fed twice daily about 8 a. m. and 4 p. m. One-half of the ration, hay in the case of Lot 1 and silage in the case of Lot 2, was given in the morning and the remainder in the afternoon, the steers in Lot 3 being given corn silage alone in the

morning and corn stover and straw in the afternoon. The ear corn fed during the last few weeks to Lots 1 and 5 was chopped and given at one feed in the morning. The corn stover and straw were mixed together in equal quantities and run through a feed cutter before being fed. Where corn stover, hay, and straw were used, as in Lot 5 the last year, the feeds were fed separately in equal parts. The steers were allowed to run in the lots surrounding the barns about three hours each afternoon. If the weather was inclement they were left out only long enough to get water. The cattle were weighed every 28 days, early in the morning before being fed or watered.

The steers in Lot 4 each year, which were winter-grazed, had no shelter on pasture except the windbreaks furnished by the trees, hills, and mountains. During snowy weather, however, they were fed at the barn on a light ration of corn stover, straw and ear corn. As soon as the snow melted they were taken back to the pasture.

The steers were changed from the wintering rations in the spring as early as the grass would carry them without injury to its subsequent growth. They were given salt in the pasture once every week.

During the summers they were driven from the pastures to the scales once every four weeks and weighed as early as it was possible to round them up in the morning. Then they were immediately driven back to the pasture. The cattle were numbered with a tag in each ear for identification in keeping individual weights. They were given approximately 3 acres of pasture per steer.

I. WINTER RATIONS AND THEIR INFLUENCE ON PASTURE GAINS OF 2-YEAR-OLD STEERS.

QUANTITY OF FEED CONSUMED.

The reader should keep in mind that it was not intended to do more than to keep the steers in good, thrifty, growing condition. It was expected they would lose some weight during the wintering period. Table 2 shows the total amount of feed consumed and the average daily ration per steer during each of the three winters.

The various digressions from the rations specified in Table 2 were necessary either to supplement the standard ration, as in the case of the mixed hay each year, the stover hay and straw the last year, and the winter pasture when it was covered with snow, so that the steers would not lose too heavily in weight, or to supplement or replace some feed the supply of which failed to last throughout the feeding period, as in the case of the silage each year. The unusual severity of the winter of 1917-18 made it necessary to feed the winter-grazed cattle supplemental feed twice as many days as in 1916-17 and 1918-19.

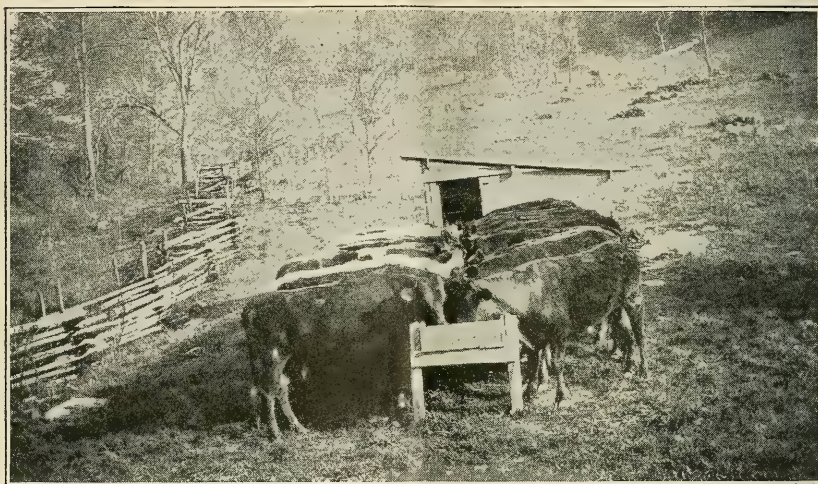


FIG. 4.—Showing condition of steers at end of winter period.

TABLE 2.—Average total and daily rations for three winters.

Lot No.	Ration.	Season.	Steers in lot.	Total feed per steer.	Daily feed per steer.
1	Mixed hay ¹	1916-17	28	<i>Pounds.</i> 1,470	<i>Pounds.</i> 11.67
		1917-18	25	1,260	10.00
		1918-19	25	1,428	11.33
		Average.....		1,389	11.03
2	Corn silage ²	1916-17	25	3,710	29.44
		1917-18	25	2,800	28.57
		1918-19	25	3,094	24.56
		Average for 1916-17 and 1918-19.....		3,402	27.00
3	Corn silage, ³ stover and straw.....	1916-17	25	1,890	15.00
				826	6.56
		1917-18	30	1,960	15.55
				728	5.78
		1918-19	30	1,890	15.00
				749	5.94
	Average silage.....			1,915	15.20
	Average stover and straw.....			764	6.07
4	Winter pasture ⁴	1916-17	17		
		1917-18	40		
		1918-19	25		
		1918-19	20	1,260	10.00
5	Stover, hay, and straw ⁵				

¹ Lot 1 received 2 pounds of ear corn per steer per day, or a total of 42 pounds, during the last 21 days in 1916-17, and 2 pounds per steer per day, or a total of 84 pounds, during the last 42 days in 1917-18 and 1918-19.

² As silage was not fed during the last 14 days in 1916-17 and only a half ration was fed the preceding 28 days, each steer received an average ration of 8.67 pounds, or a total of 364 pounds, of corn stover during the last 42 days, and 2 pounds, or a total of 28 pounds, of ear corn and one-half pound, or a total of 7 pounds, of cottonseed cake during the last 14 days. In 1917-18 the steers were turned on pasture the last 28 days of the winter period because there was not sufficient silage for them. An increase of 59 pounds in weight this last month accounts for the small loss for the entire winter period. In 1918-19, to make the silage hold out 6.25 pounds daily, or a total of 175 pounds, of corn stover and straw were fed from the seventieth to the ninety-eighth day.

³ As silage was not fed during the last 14 days, the stover and straw was increased to 12 pounds per steer daily; and 2 pounds daily, or a total of 28 pounds, of ear corn and one-half pound daily, or a total of 7 pounds, of cottonseed cake per steer were added in 1916-17.

⁴ While snow was on the ground the steers in Lot 4 were given a ration of 10 pounds, or a total of 190 pounds, of mixed hay for 19 days in 1916-17; 9.22 pounds, or a total of 341 pounds, of corn stover and straw for 37 days in 1917-18; 8.44 pounds, or a total of 135 pounds, of corn stover and straw, and 2 pounds, or a total of 32 pounds, of ear corn for 16 days in 1918-19.

⁵ Two pounds of ear corn per steer per day, or a total of 84 pounds, were fed to Lot 5 during the last 42 days in 1918-19.

LOSSES DURING WINTER.

Table 3 shows the average total and daily loss of weight per steer during each of the three winters.

TABLE 3.—*Total and daily losses during three winters.*

Lot No.	Ration.	Season.	Steers in lot.	Average initial weight per steer.	Average final weight per steer.	Total loss per steer.	Daily loss per steer.
				<i>Pounds.</i>	<i>Pounds.</i>	<i>Pounds.</i>	<i>Pound.</i>
1	Mixed hay.....	1916-17	28	794	759	35	0.27
		1917-18	25	780	728	52	.41
		1918-19	25	768	704	64	.51
	Average.....			781	731	50	.39
2	Corn silage.....	1916-17	25	773	721	52	.41
		1917-18	25	747	744	3	.02
		1918-19	25	782	718	64	.51
	Average.....			768	728	40	.31
3	Corn silage, stover, and straw.....	1916-17	25	787	711	76	.60
		1917-18	30	755	683	72	.57
		1918-19	30	767	681	86	.68
	Average.....			769	691	78	.62
4	Winter pasture.....	1916-17	17	781	763	18	.14
		1917-18	40	737	728	9	.07
		1918-19	25	770	702	68	.54
	Average.....			756	727	29	.23
5	Stover, hay, and straw.....	1918-19	20	757	693	64	.51

The mixed-hay-fed steers lost quite uniformly each year. The losses of the silage-fed steers are irregular on account of Lot 2 having been turned on pasture for the last month in 1917-18. The silage, stover, and straw-fed cattle lost most heavily each year.

The winter-grazed steers lost least of all the first year, and practically the same as the other lots the third year. They lost considerably less than any of the barn-fed cattle, taking the average for three winters. Close comparisons of the gains of various lots by years can not be made in many instances on account of the irregular supplemental and substituted rations.

Although all the cattle lost in weight during the three years' work, they came through the winter in exceptionally thrifty condition, considering the amount of feed given (see fig. 4). In fact, they were wintered much better than the average stockman winters his cattle. When they were turned on pasture the following summer they made excellent gains from the beginning.

GAINS DURING SUMMER.

Table 4 gives the average initial and final weights per steer in each of the lots and the total and average daily gains per steer for each of the three summer periods.

The winter-grazed steers which had come through the winter in the best condition made the least gain during the following summer, as the averages in Table 4 show.



FIG. 5.—One of the winter-grazed steers (Lot 4) at the end of the summer period.

TABLE 4.—*Total and daily gains during three summers.*

Lot No.	Winter ration.	Season.	Steers in lot.	Average initial weight per steer.	Average final weight per steer.	Total average gain per steer.	Average daily gain per steer.
				<i>Pounds.</i>	<i>Pounds.</i>	<i>Pounds.</i>	<i>Pounds.</i>
1	Mixed hay.....	1916-17	28	759	1,071	312	2.23
		1917-18	25	728	1,077	349	2.49
		1918-19	25	704	1,056	353	2.52
	Average.....			731	1,068	337	2.41
2	Corn silage.....	1916-17	25	721	1,071	350	2.50
		1917-18	25	744	1,060	316	2.26
		1918-19	25	718	1,060	342	2.44
	Average.....			728	1,064	336	2.40
3	Corn silage, stover, and straw.....	1916-17	25	711	1,023	312	2.23
		1917-18	30	683	1,036	353	2.52
		1918-19	30	681	1,031	350	2.50
	Average.....			691	1,031	340	2.43
4	Winter pasture.....	1916-17	17	763	1,097	334	2.39
		1917-18	40	728	1,041	314	2.24
		1918-19	25	702	1,067	365	2.61
	Average.....			727	1,060	333	2.38
5	Stover, hay, and straw.....	1918-19	20	693	1,040	347	2.48

LOSSES AND GAINS, WINTER AND SUMMER.

The average winter losses and the average total gains for winter and summer are given in Table 5.

TABLE 5.—*Summary of losses and gains, winter and summer.*

Lot No.	Ration.	Year.	Loss in weight per steer in winter.	Gain in weight per steer in summer.	Daily gain in summer.	Total gain in weight per steer, winter and summer.	Daily gain, winter and summer.
			<i>Pounds.</i>	<i>Pounds.</i>	<i>Pounds.</i>	<i>Pounds.</i>	<i>Pounds.</i>
1	Mixed hay.....	1916-17	35	312	.....	277	.....
		1917-18	52	349	.....	297	.....
		1918-19	64	352	.....	288	.....
	Average.....		50	337	2.41	287	1.12
2	Corn silage.....	1916-17	52	350	.....	298	.....
		1917-18	3	316	.....	313	.....
		1918-19	64	342	.....	278	.....
	Average.....		40	336	2.40	296	1.16
3	Corn silage, stover, and straw.....	1916-17	76	312	.....	236	.....
		1917-18	72	353	.....	281	.....
		1918-19	86	350	.....	264	.....
	Average.....		78	340	2.43	262	1.02
4	Winter pasture.....	1916-17	18	334	.....	316	.....
		1917-18	9	314	.....	304	.....
		1918-19	68	365	.....	297	.....
	Average.....		29	333	2.38	304	1.19
5	Stover, hay, and straw.....	1918-19	64	347	2.48	283	1.10

The winter-grazed steers made the greatest total gain for the winter and summer periods combined, as was the case during the first three years' work. The rations of Lots 1, 2, and 3 are not directly comparable to the lots wintered on harvested crops during the first three years' work.

GRAPHIC PRESENTATION OF LOSSES AND GAINS.

The comparative rapidity and extent of gains and losses can be shown more clearly by the use of a chart, figure 4, than in any other way. It shows the average changes in weight of the steers of the four lots.

The average length of the total period for three years was 266 days, of which 126 days were in the winter, or feeding, period, and the remaining 140 in the summer, or grass, period. The heavy, black, vertical line near the center of the chart marks the dividing line between the winter and summer periods. The other vertical lines represent 28-day periods with the exception of the last period during the winter, which was only 14 days. The horizontal lines on the chart represent pounds of gain or losses, as the case may be. The diagonal lines representing the various lots of cattle show losses in weight when they go downward and gains in weight when they go upward.

It will be noted that during the winter period all the lots lost considerable weight during the first 28 days, and, excepting the last 14 days, the two silage-fed lots lost more than the others. During the second, third, and fourth months all the lots lost quite uniformly

excepting the hay-fed cattle, which gained some during the second month. The gain in weight during the last 14 days of the winter period is due, apparently, to slight increases in the rations as noted

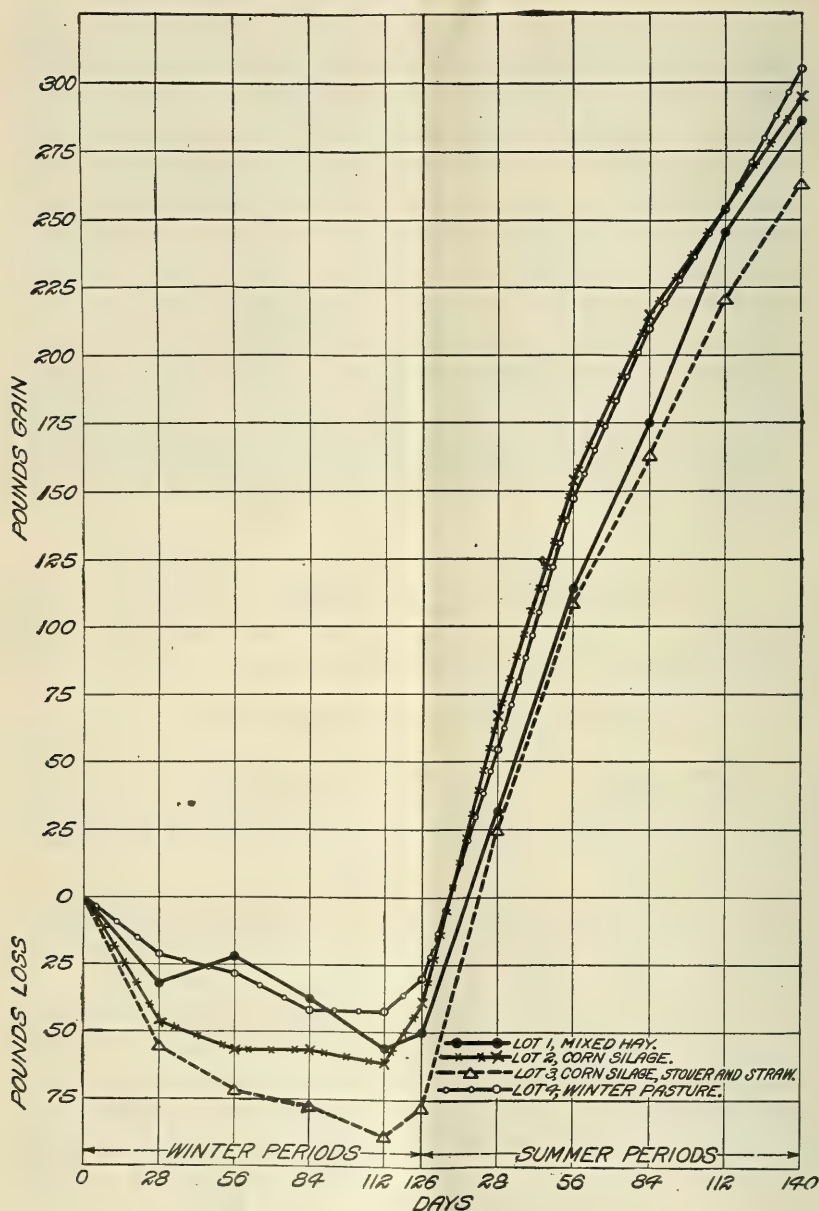


FIG. 6.

under Table 2. In the case of the steers on winter pasture, the new growth of grass is obviously the cause for their beginning to gain in weight during the last 14 days.

During the summer period there are no significant variations in the gains made by the different lots. The silage, stover, and straw-fed cattle, which had lost the most during the winter, made the greatest gain during the first month on summer pasture. At the end of the summer period the lots have practically the same relative positions on the chart as they had at the beginning of the summer period.

CONCLUSIONS.

The six years' work as described in this bulletin and in Department of Agriculture Bulletin 628, serves as a basis for the following conclusions:

1. About 2 acres of the average cut-over land in western North Carolina when properly seeded to pasture will keep a steer in good condition during the winter.

2. About 3 acres of the same land will graze a steer satisfactorily during the summer months, producing 300 to 350 pounds of gain. In other words, 5 acres of pasture will keep a steer one year and produce 250 to 300 pounds of gain in live weight.

3. Steers on winter pasture will stay in better condition throughout the winter and will be better finished the following fall than steers wintered on coarse, harvested feeds.

4. According to the data given in Tables 2 and 3 of this bulletin, 2 acres of winter pasture, supplemented by 220 pounds of mixed hay, stover, and straw and 10 pounds of ear corn for 24 days when snow covers the ground, are better than the following quantities of feed for keeping a steer through the winter:

(a) 1,400 pounds of mixed hay and 70 pounds of ear corn.

(b) 3,400 pounds of corn silage, 270 pounds of stover and straw, and 20 pounds of ear corn.

(c) 1,900 pounds of silage, 760 pounds of stover and straw, and 15 pounds of ear corn.

5. With a little work and expense to secure proper seeding, much of the cut-over land in the Appalachian region south of Kentucky and Virginia, can be converted into winter pastures suitable for either beef cattle or sheep.

II. COST OF WINTERING AND FATTENING STEERS ON GRASS THE FOLLOWING SUMMER.

While the conversion of waste cut-over land into winter pasture is a way whereby more cattle can be kept through the winter, the use of corn silage also has possibilities. It takes about 1 acre to produce sufficient hay to carry a steer through the winter, but the same acre in corn will produce sufficient corn silage to feed from three to four steers through the winter. Of course, in this region there is much land better adapted to the production of hay than of corn silage.

Most cattle grazers in the areas of good pasture want to know whether to buy their steers in the fall or in the spring just before the grass season opens. Some may make greater profits by buying in the fall and others by buying in the spring, but there is no general rule in regard to the best time to buy stockers and feeders. Of course, the men who can harvest and store suitable feeds for wintering cattle at a reasonable cost should, and do, usually buy in the fall. In the spring, when the grass is ready, the demand for cattle usually makes them cost more than the expense of wintering justifies. Even in case of a falling market, the men who have bought in the fall have used, chiefly, feed for which there was no other market.

It has already been shown how the different methods of wintering and the various quantities of feed affect the weights of steers during the winter and how these methods and feeds affect the gains made on grass the following summer. In the following discussion, an effort is made to compare the costs and financial returns of the various rations and methods used in the experimental work. It is felt, however, that this is the most questionable and unsatisfactory part of such experimental work and that this is especially true for the last few years because of the unusual fluctuations which have occurred in feed prices. The farm price of corn in this section of the country increased from \$1 per bushel in 1916 to \$1.67 per bushel in 1918, and hay increased from \$15.35 to \$23.54 per ton. To have the costs and returns uniform for making comparisons of the results obtained in the various years and to simplify the calculations, average prices are used.

PRICES OF FEEDS.

According to data reported by field representatives of the Bureau of Crop Estimates and published in the Yearbook, United States Department of Agriculture, the average farm price on December 1, 1916, 1917, and 1918, in North Carolina, South Carolina, Georgia, Tennessee, Kentucky, West Virginia, and Virginia for corn is \$1.40 per bushel and for hay is \$19.75 per ton. We have used \$1.35 as the value of corn in the silage, as it often is of a poorer quality than that which is marketed. For convenience \$20 per ton is used for the hay. As no official figures are available for the other feeds they must be estimated, using as a basis local prices where the cattle were fed. Straw and stover, accordingly, are valued at \$10 per ton. This necessitates using \$13.33 as the price for the mixture of equal parts of corn stover, hay, and straw.

As a general rule, a ton of corn silage contains 5 bushels of corn, making it worth \$6.75 on the basis of the corn content. On the average the weight of ear corn is equal to the weight of stover. (This ratio of 1 to 1 has been adopted by the Office of Farm Management.) Since 5 bushels of ear corn weigh 350 pounds, the stover equivalent of 1 ton of corn silage is 350 pounds. At \$10 per ton this is worth

\$1.75, making the total farm value of the silage \$8.50. The prices of \$1.50 per head for 28 days for pasture and \$50 per ton for cotton-seed cake are applicable to local conditions, and are practically in proportion to the prices taken from the Yearbook. The actual costs and selling prices of the steers are used in determining the corresponding averages.

The average prices used for the feeds and the cattle are as follows:

Ear corn, \$1.40 per bushel.

Corn silage, \$8.50 per ton.

Hay, \$20 per ton.

Corn stover and straw, \$10.

Corn stover, hay, and straw, \$13.33 per ton.

Pasture, \$1.50 per head per 28 days.

Initial cost of the steers, \$7.833 per hundredweight.

Selling price, \$10.166 per hundredweight.

If the prices of feed are relatively different in any locality where the results of this bulletin are being applied, it is suggested that they be substituted, using the quantities of feed in Table 2, page 8, as a basis for the calculations and the following tables as a guide for making various comparisons. Lot 5 is disregarded throughout the discussion because it represents the results of only one year's work.

AVERAGE COST OF WINTERING.

Table 6 shows the loss of weight and average cost of wintering each steer, the cost in spring per hundredweight, and the advance in spring cost over the initial cost per hundredweight.

TABLE 6.—*Cost of wintering and spring costs per hundredweight.*

Lot No.	Ration.	Year.	Loss per steer.	Cost to winter per steer.	Cost in spring per cwt.	Advance in spring cost over initial cost per cwt.
			<i>Pounds.</i>			
1	Mixed hay	1916-17	35	\$15.54	\$10.24	\$2.41
		1917-18	52	14.28	10.35	2.52
		1918-19	64	15.96	10.81	2.98
	Average.....		50	15.27	10.46	2.63
2	Corn silage	1916-17	52	18.32	10.94	3.11
		1917-18	3	13.40	9.67	1.84
		1918-19	64	14.02	10.48	2.65
	Average.....		40	15.25	10.36	2.53
3	Corn silage, stover, and straw	1916-17	76	12.89	10.48	2.65
		1917-18	72	11.97	10.41	2.58
		1918-19	86	12.06	10.59	2.76
	Average.....		79	12.27	10.49	2.66
4	Winter pasture	1916-17	18	8.65	9.15	1.32
		1917-18	9	8.45	9.09	1.26
		1918-19	68	8.06	9.74	1.91
	Average.....		29	8.38	9.30	1.47
5	Stover, hay, and straw	1918-19	64	10.08	10.01	2.18

As Table 6 shows, the mixed hay and the silage-fed steers cost the same to winter; while the silage, stover, and straw-fed cattle cost \$3 per head less, and the winter-grazed steers cost only 75 cents more than half as much as the hay and silage-fed steers. The spring cost per hundredweight was practically the same for the barn-wintered steers and \$1 less for the winter-grazed steers.

COST PER POUND OF GAIN.

The cost of producing a pound of gain is one of the main factors in determining whether or not a steer returns a profit. Knowing the original weight and cost, the gain in weight, and the cost of gain, the amount for which the steer must sell to break even or return a profit can be calculated. When the sum of the cost of wintering and the cost of summer pasture is divided by the total gain in weight, the cost of a pound of gain is obtained. Table 7 gives the cost per pound of gain, and related factors.

TABLE 7.—*Summary of weight gains and costs per pound of gain.*

Lot No.	Ration.	Year.	Total gain per steer each summer.	Cost per pound of gain in summer. ¹	Total cost of feed and pasture per year per steer. ²	Total yearly gain per steer.	Cost per pound of yearly gain.
			<i>Pounds.</i>			<i>Pounds.</i>	
1	Mixed hay.....	1916-17	312	\$0.024	\$23.04	277	\$0.083
		1917-18	349	.021	21.78	297	.073
		1918-19	352	.021	23.46	288	.081
		Average.....	337	.022	22.77	287	.079
2	Corn silage.....	1916-17	350	.021	25.82	298	.087
		1917-18	316	.024	20.90	313	.067
		1918-19	342	.022	21.52	278	.077
		Average.....	336	.022	22.75	296	.077
3	Corn silage, stover, and straw.....	1916-17	312	.024	20.39	236	.086
		1917-18	353	.021	19.47	281	.069
		1918-19	350	.021	19.56	264	.074
		Average.....	340	.022	19.77	262	.076
4	Winter pasture.....	1916-17	334	.022	16.15	316	.051
		1917-18	314	.024	15.95	304	.052
		1918-19	365	.021	15.56	297	.052
		Average.....	333	.023	15.88	304	.052
5	Stover, hay, and straw.....	1918-19	347	.022	17.58	283	.062

¹ The average charge for pasture for each year is \$1.50 per month, which makes a total of \$7.50 per steer.

² The cost each summer is added to the winter cost as given in Table 6.

In Table 7, as the charge for pasture during the summers is the same for all the lots, and as the steers made approximately the same gains during that time, there is no apparent variation in the cost per pound of gain during that time. The cost per pound of gain for the winter and summer periods combined is practically the same for the steers that were wintered on harvested feeds, while the cost per pound of gain for the winter-grazed steers is only two-thirds as much. Such

a result strongly favors the use of winter pastures. The results with the lots fed during the winter on harvested feeds is slightly in favor of the use of silage.

PROFIT PER STEER.

Like most other productive operations, the profit or loss in dollars and cents is the usual index of the success or failure with cattle feeding. The average cattleman must make an average profit over a period of years to enable him to stay in the business. Unusual profits are offset by corresponding losses. The successful cattleman usually stays with the game year by year, with due regard for general economic conditions. In times of falling prices he must curtail his operations; in times of rising prices he must not be a plunger, for he may be caught by a large and sudden drop in prices. The large profits shown in Table 8 are due to the fact that cattle prices were going up throughout the period in which the work was done.

On an average for the three years, the steers which were bought as stockers for \$7.833 per hundredweight sold as feeders 266 days later for \$10.167, which is practically 30 per cent more than they cost per hundredweight. With the exception of the winter-grazed steers, the gain in weight cost practically the same per pound as the original weight. As is customary in cattle feeding, the labor and other incidental expenses are considered as balancing the manure produced by the steers.

TABLE 8.—*Total winter and summer costs and profit per steer.*

Lot No.	Winter ration.	Year.	Initial value per steer.	Cost to winter per steer.	Cost per steer in the spring.	Cost per steer in the fall. ¹	Net sale price per steer. ²	Profit per steer.
1	Mixed hay	1916-17	\$62.20	\$15.54	\$77.74	\$85.24	\$108.89	\$23.65
		1917-18	61.10	14.28	75.38	82.88	109.50	26.62
		1918-19	60.16	15.96	76.12	83.62	107.36	23.74
	Average.....		61.19	15.27	76.46	83.96	108.59	24.63
2	Corn silage	1916-17	60.55	18.32	78.87	86.37	108.89	22.52
		1917-18	58.51	13.40	71.91	79.41	107.77	28.36
		1918-19	61.26	14.02	75.28	82.78	107.77	24.99
	Average.....		60.11	15.25	75.35	82.85	108.14	25.29
3	Corn silage, stover, and straw	1916-17	61.65	12.89	74.54	82.04	104.01	21.97
		1917-18	59.14	11.97	71.11	78.61	105.33	26.72
		1918-19	60.08	12.06	72.14	79.64	104.82	25.18
	Average.....		60.21	12.27	72.48	79.98	104.76	24.78
4	Winter pasture	1916-17	61.18	8.65	69.83	77.33	111.53	34.20
		1917-18	57.73	8.45	66.18	73.68	105.83	32.15
		1918-19	60.32	8.06	68.38	75.88	108.48	32.60
	Average.....		59.23	8.38	67.61	75.11	107.82	32.71
5	Stover, hay, and straw	1918-19	59.30	10.08	69.38	76.88	105.73	28.85

¹ A pasture charge of \$1.50 per month of 28 days for 5 months, making a total of \$7.50, is added to the spring cost.

² The average actual sale price at the end of the summer period was \$10.167 per hundredweight.

As would be expected from the results given in Tables 6 and 7, the barn-wintered steers made practically the same profit per head while the winter-grazed steers made approximately one-third more profit per head than any of the barn-wintered steers.

SUMMARY OF GAINS AND COSTS.

In Table 9 a general summary of costs and gains, winter and summer, is given. The figures represent the averages of the three years for each lot.

TABLE 9.—General summary of costs and gains, winter and summer.

Item.	Lot 1: mixed hay.	Lot 2: corn silage.	Lot 3: corn silage, stover, and straw.	Lot 4: winter pasture.	Lot 5 (only 1 year); stover, hay, and straw.
Winter period (126 days):					
Loss in weight per steer.....pounds..	50	40	79	29	64
Cost to winter per steer.....	\$15. 27	\$15. 25	\$12. 27	\$8. 38	\$10. 08
Cost per day per steer.....	\$0. 121	\$0. 121	\$0. 097	\$0. 066	\$0. 080
Summer period (140 days):					
Total gain per steer.....pounds..	337	336	340	333	347
Cost per day per steer ¹	\$0. 053	\$0. 053	\$0. 053	\$0. 053	\$0. 053
Cost per pound of gain.....	\$0. 022	\$0. 022	\$0. 022	\$0. 022	\$0. 022
Winter and summer (266 days):					
Total gain per steer.....pounds..	287	296	262	304	283
Total cost per steer.....	\$22. 77	\$22. 75	\$19. 77	\$15. 88	\$17. 58
Cost per pound of gain.....	\$0. 079	\$0. 077	\$0. 076	\$0. 052	\$0. 062
Full year (365 days):					
Total cost per head ²	\$28. 07	\$28. 05	\$25. 07	\$21. 18	\$22. 88
Cost per day.....	\$0. 077	\$0. 077	\$0. 069	\$0. 058	\$0. 063

¹ The total cost per summer period of 140 days is \$7.50 for each lot.

² In this experimental work the cattle were carried only 266 days each year (from about Dec. 15 to Sept. 6). In finding the cost per day for 365 days, the winter cost per day for 126 days is used with \$0.53 per day for the balance of the year (239 days). From September to December, such cattle are usually on pasture which maintains their weight.

CONCLUSIONS.

1. The average costs and gains for the steers wintered on mixed hay are practically the same as for those wintered on corn silage.
2. Corn silage, stover, and straw proved to be a considerably cheaper ration than either mixed hay or corn silage alone.
3. Winter pasture was the most satisfactory ration of all, both in cheapness and total gain in weight throughout the year.
4. The average winter cost for four months for all the rations was one-half of the total cost for 12 months.
5. The average increase in cost per hundredweight of all the steers in the spring was 30 per cent greater than their cost in the fall, while the average loss in weight was 6.5 per cent.

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UNITED STATES DEPARTMENT OF AGRICULTURE



BULLETIN No. 955

Contribution from the Bureau of Animal Industry
JOHN R. MOHLER, Chief



Washington, D. C.



May 16, 1921

UNIT REQUIREMENTS FOR PRODUCING MARKET MILK IN SOUTHEASTERN LOUISIANA.¹

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CHARACTER AND SCOPE OF THE WORK.

How many pounds of grain, hay, and silage and how many hours of labor does it take to produce 100 pounds of milk in the different dairy sections of the United States? How much does it cost for buildings, equipment, and the general expenses of the dairy? The answers to these questions should be of interest and value to dairy-men throughout the country. In 1915 the Bureau of Animal Industry, United States Department of Agriculture, began a series of studies on groups of dairy farms in different sections of the United States to obtain accurate information along these lines. The first step taken was to develop a system whereby the actual cost of producing milk could be obtained month by month on practical dairy farms in market milk centers of the United States.

Investigations have been completed and the results published for northwestern Indiana (Department Bulletin 858), North Carolina,²

¹ The data in this bulletin apply especially to milk shipped from this section to the New Orleans market.

² A bulletin on this investigation was published by the North Carolina Department of Agriculture.

western Washington (Department Bulletin 919), and Vermont (Department Bulletin 923). This bulletin deals with the conditions in the vicinity of New Orleans, La. The work was organized among a group of 17 dairymen living in Tangipahoa Parish, La., in March, 1918. The specialist of the department made monthly visits to each farm for two years, until April, 1920. This locality was selected because the farms are typical of conditions found in that section and the milk is shipped to a large city market, New Orleans.

Although the figures obtained show what was required to produce market milk under the system of dairy management found in the section studied, and probably approximate the requirements in similar sections, they, of course, do not apply to dairying in other sections, where other conditions and methods of management prevail. The dairies were subject to the inspection system controlling the sanitary conditions under which milk could be shipped and sold in the New Orleans market. The cost of production would have been somewhat different if either higher or lower grades of milk had been produced.

The results have been reported separately for the winter and summer seasons because the season of the year may have a marked influence on the principal factors of cost. Summer conditions prevail from April to September, inclusive, and winter conditions from October to March, inclusive. This division of time was used in reporting the results for the winter and summer seasons.

The various tables are based upon figures obtained during the two-year study and the weighted averages of these records were used whenever they would express the results more accurately. The weighted average was obtained by giving each item a different weight in the average according to its relative importance.

METHODS OF OBTAINING DATA.

The figures reported are based on actual records obtained by regular monthly full-day visits to 14 farms for two years and to 8 other farms for one year.

At the beginning and the end of each year the field agent took an inventory of the dairy buildings, livestock, and equipment used in the care of the herd and its products. On his regular monthly visit at each farm the agent, with watch in hand, noted and recorded the exact minute each labor operation in the dairy was begun and ended. An equally careful record was obtained of the kind, description, quantity, and cost of each feed used, the quantity of milk sold that month, and the amount received for it. In addition, the milk used by the proprietor and his help or fed to calves was measured or weighed on the monthly visit and used as a basis for determining the quantity kept on the farm during the month.

The dairyman kept itemized accounts of expenses incurred between monthly visits and reported these items to the field agent. Monthly records were also kept of the purchase or sale of cows, calves, hides, of outside bull service, and of other miscellaneous information. Accurate records of calves born and first-hand information on the condition and methods of handling manure were collected systematically.

The collection of monthly records lessened the influence of unusual circumstances at the time of any particular visit. The use of the records of all the herds for each month made it possible to obtain representative data for each month, season, and year. Records were obtained the second year as a check on the first year's work and to increase the quantity of data for study.

REQUIREMENTS FOR PRODUCING 100 POUNDS OF MILK.

To obtain more uniform results and to overcome the effect of fluctuating prices, money values have been eliminated wherever possible. Feed requirements in pounds and the labor requirements in hours make it possible to apply current prices.

TABLE 1.—Units required, except charge for management, for producing 100 pounds of milk in winter and in summer.

Item.	Winter.		Summary of two winters.	Summer.		Summary of two summers.
	1918-19.	1919-20.		1918.	1919.	
Feed:						
Purchased concentrates.....pounds..	69.9	71.7	70.8	49.8	54.5	52.2
Home-grown grains.....do.....	.9	2.4	1.6	.2	.3	.3
Total concentrates.....do.....	70.8	74.1	72.4	50.0	54.8	52.5
Hauling and grinding grain.....	\$0.072	\$0.117	\$0.095	\$0.036	\$0.062	\$0.050
Noncommercial roughage.....pounds..	8.6	19.3	14.1	.2	1.6	.9
Commercial carbohydrate hay.....do.....	6.5	23.5	15.2	.....	1.0	.5
Commercial legume hay.....do.....	8.5	9.5	9.0	.....	1.0	.5
Total dry roughage.....do.....	23.6	52.3	38.3	.2	3.6	1.9
Silage and other succulent roughage, pounds.....	80.8	76.0	78.4	12.4	4.0	8.1
Pasture.....	\$0.197	\$0.115	\$0.155	\$0.228	\$0.169	\$0.197
Bedding.....pounds..	.6		.3			
Labor:						
Human.....hours..	6.3	5.3	5.8	5.2	4.7	5.0
Horse.....do.....	.9	.8	.9	.6	.7	.7
Other costs:						
Building charges.....	\$0.318	\$0.194	\$0.255	\$0.215	\$0.130	\$0.171
Equipment charges and dairy supplies.	.343	.344	.344	.231	.230	.230
Herd charges—						
Taxes, insurance, veterinary, medicines, and disinfectants.....	.069	.094	.082	.047	.063	.055
Interest on cow investment.....	.208	.242	.225	.140	.162	.151
Cost of keeping bull.....	.087	.078	.082	.030	.043	.037
Motor-truck charge.....	.001	.016	.009	.001	.005	.003
Cash hauling of milk.....					.012	.006
Total of other costs except depreciation on cows.....	1.026	.963	.997	.664	.645	.653
Depreciation on cows.....	.271	.177	.223	.183	.119	.150
Total of other costs.....	1.297	1.145	1.220	.847	.764	.803

Table 1 shows that a large quantity of grain and small quantities of dry roughage and silage were fed for each 100 pounds of milk produced in winter. A large quantity of grain was fed in summer also. The amount of grain per cow per year was not excessive, but the small quantity of milk produced tended to increase the grain per 100 pounds of milk. The quantity of grain, however, could have been materially reduced had more roughage been fed.

DESCRIPTION OF THE HERDS.

During the first year the 17 herds had a total of 452 cows with an average yearly production of 2,994 pounds of milk, testing 4.6 per cent butterfat. The second year's study included 440.6 cows with an average yearly production of 3,263 pounds of milk having an average butterfat test of 4.2 per cent.

A large proportion of the cows were so-called "native" stock. Many of the herds, however, had cows showing some Jersey characteristics, and the milk production of most of the herds is being increased by the use of purebred bulls of the dairy breeds. The eradication of the cattle tick from this section has also increased the yearly milk production of the cows.

REQUIREMENTS FOR KEEPING A COW ONE YEAR.

The quantity of milk produced, as shown in Table 2, was slightly greater in summer than in winter, but the quantity of grain fed per cow was practically the same for both seasons.

The beneficial effect of pasture is shown in Table 2 in the comparative quantities of dry roughage and silage fed in the winter and summer seasons. It is the custom to allow some of the herds to range over the "Piney-Woods" pasture, which furnishes fair grazing.

Owing to the mild, open winters, the quantity of bedding used is so small as to be negligible.

CREDITS FOR MANURE AND CALVES.

The method followed for obtaining the value of manure takes into consideration the fertilizing constituents of the feeds fed, as obtained from standard tables showing the fertilizing constituents returned in the individual feeds consumed.

About three-fourths of the protein in the feeds fed to dairy cows passes through the body and is voided in the manure. This protein is a source of nitrogen which is valuable as fertilizer. The same is also true of phosphoric acid and potash. Practically every dairy farm has use for all manure voided by the herd. The commercial value of the manure depends upon the use to which it is put. The returns in dollars depend upon the increase in the crops raised and in the amount received from the sale of these crops. These facts may

reduce or increase the value of a ton of manure below or above the market price of the fertilizing constituents contained in it.

TABLE 2.—*Number of cows, average production, and requirements for keeping a cow during each season and for the entire year, except charge for management.*

Item.	Winter.	Summer.	Entire year.
Number of cows	855.9	929.4	892.6
Average production per cow.....pounds.	1,309	1,797	3,106
Feed:			
Purchased concentrates.....do.....	927	939	1,866
Home-grown grains.....do.....	22	5	27
Total concentrates.....do.....	949	944	1,893
Hauling and grinding grain.....do.....	\$1.25	\$0.89	\$2.14
Noncommercial roughage.....pounds.	185	17	202
Commercial carbohydrate hay.....do.....	200	9	209
Commercial legume hay.....do.....	118	9	127
Total dry roughage.....do.....	503	35	538
Silage and other succulent roughage.....do.....	1,026	145	1,171
Bedding.....do.....	4		4
Pasture.....do.....	\$2.03	\$3.55	\$5.58
Labor:			
Human.....hours.....	75.3	89.2	164.5
Horse.....do.....	11.6	12.1	23.7
Other costs:			
Building charges.....do.....	\$3.33	\$3.07	\$6.40
Equipment charges and dairy supplies.....do.....	4.50	4.14	8.64
Herd charges—			
Taxes, insurance, veterinary, medicines, and disinfectants.....do.....	1.07	.99	2.06
Interest on cow investment.....do.....	2.95	2.72	5.67
Cost of keeping bull.....do.....	1.08	.66	1.74
Motor-truck charge.....do.....	.12	.05	.17
Cash hauling of milk.....do.....		.11	.11
Total of other costs except depreciation on cows.....do.....	13.05	11.74	24.79
Depreciation on cows.....do.....	2.92	2.69	5.61
Total of other costs.....do.....	15.97	14.43	30.40

The value of a ton of manure, which was considered to be the same for summer and winter, was based on the market price of the fertilizing constituents contained in it, which were as follows: Nitrogen, \$0.375 a pound; commercial phosphoric acid, \$0.075 a pound; and potash, \$0.275 a pound.

Only that manure which was saved or which could have been saved by using reasonable care with the equipment available was credited to the cows. It was not possible to weigh the quantity of manure dropped by each herd, but a record was kept of the time the cows were actually in the stables. This made it possible to figure the weight of the manure voided in the barns, for, according to the best authorities, a 1,000-pound cow will produce 13 tons of manure in a year, or 6½ tons in 6 months. The manure dropped on pasture was not credited to the herds. If a credit had been given, then an offset charge for fertilizer against pasture would have been necessary.

Since a cow during digestion utilizes on the average only approximately 25 per cent of the nitrogen, 30 per cent of the phosphorus,

and 15 per cent of the potash, it is evident that 75 per cent of the nitrogen, 70 per cent of the phosphorus, and 85 per cent of the potash is available for fertilizers.

TABLE 3.—*Credits for manure and fertilizing constituents during the two winters and the two summers.*

Item.	Winter.			Summer.		
	1918-19	1919-20	Average.	1918	1919	Average.
Total manure saved.....tons..	355.2	360.2	357.7	329.8	314.6	322.2
Manure per cow.....pounds..	1,620	1,740	1,680	1,420	1,340	1,380
Manure credited per 100 pounds of milk, pounds.....	130.4	125.1	127.7	81.6	74.8	78.2
	Winter average.			Summer average.		
	Nitrogen.	Phos- phoric acid.	Potash.	Nitrogen.	Phos- phoric acid.	Potash.
Fertilizing constituents in manure, pounds.....	3,148	1,180	1,860	2,822	1,073	1,678
Credit per cow.....pounds..	7.4	2.8	4.3	6.1	2.3	3.6

When obtaining the quantity of manure saved, a number of factors were taken into consideration—the time the cattle were out of the stables, making the manure unreclaimable; the quantity of liquid lost through leaks in the gutters; and the loss from leaching while exposed to the weather.

According to the method used for determining it, a ton of average manure saved was computed to contain the following fertilizing constituents:

Nitrogen.....	8.8 pounds.
Commercial phosphoric acid.....	2.3 pounds.
Potash.....	5.2 pounds.

The demand for newborn calves was very limited and many calves were given away, nothing being received in return. This accounts for the low credit of \$1.60 per cow for the first year and \$3.01 for the second year.

TABLE 4.—*Credits by years and by seasons for calves produced.*

Item.	Year.		Credit by seasons.	
	1918-19	1919-20	Both winters.	Both summers.
Number of calves.....	404	351	267	388
Total value of calves.....	\$724.75	\$1,325.59	\$985.00	\$1,065.34
Average value of calves.....	\$1.79	\$3.78	\$2.68	\$2.75
Calves per cow.....	0.89	0.80	0.43	0.42
Credit per cow.....	\$1.60	\$3.01	\$1.15	\$1.15
Credit per 100 pounds of milk.....	0.030 of 1 calf.	0.024 of 1 calf.	0.033 of 1 calf.	0.023 of 1 calf.

REQUIREMENTS FOR KEEPING A BULL.

There is a noticeable difference between winter and summer in the feed and pasture requirements for a bull. The quantity of bedding is so small as to be negligible, and is due to the fact that only a few bulls received any bedding at all and then only for short periods in the winter.

Many of the bulls retained in the herds increased in value during the year and some bulls sold for beef during the year brought more than their inventory value at the beginning of the year. These conditions were brought about mainly by the unusual conditions incident to the war period.

TABLE 5.—Requirements for keeping a bull, by seasons, based on averages obtained from the equivalent of 24.3 bulls.

Item.	Winter.	Summer.	Entire year.
Feed:			
Purchased concentrates.....pounds..	667	459	1,126
Home-grown grain.....do.....	54	22	76
Total concentrates.....do.....	721	481	1,202
Hauling grain.....do.....	\$0.58	\$0.49	\$1.07
Noncommercial roughage.....pounds..	206	206	206
Commercial carbohydrate hay.....do.....	170	136	306
Commercial legume hay.....do.....	230	37	267
Total dry roughage.....do.....	606	173	779
Succulent roughage.....do.....	972	154	1,126
Bedding.....do.....	4	4	4
Pasture.....do.....	\$1.18	\$3.48	\$4.66
Human labor.....hours.....	17.4	16.2	33.6
Other costs:			
Interest on bull investment.....	\$8.21	\$7.53	\$15.74
Bull's share of buildings.....	3.94	3.61	7.55
Charges for outside bull service.....		.11	.11
Total of other costs.....	12.15	11.25	23.40
Appreciation.....	10.89	10.00	20.89
Total of other costs less appreciation.....	1.26	1.25	2.51

FACTORS INVOLVED IN THE PRODUCTION OF MILK.

FEEDS.

Concentrates is a term applied to grain, cereals, or seeds, or to by-products containing a large quantity of nutritious substance in a relatively small bulk.

Home-grown grains refer to concentrates grown on the farm or in the locality where fed.

Dry roughage includes various hays and other bulky feeds which are subdivided into three classes: (1) Noncommercial dry roughage, coarse feeds, such as corn stover and oat hay, which ordinarily could not be sold in large quantities on the city markets, and hay or other dry roughage so foul with weeds or so damaged in curing as not to be readily salable; (2) commercial leguminous roughage, which

includes alfalfa, cowpea, lespedeza, and other marketable legume hays when pure, or when so slightly mixed with grasses as not materially to affect the protein content; and (3) commercial carbohydrate hay, which refers to all marketable hays except those classified as commercial leguminous roughage.

Succulent roughage consists of silage and such feeds as sweet potatoes and soiling crops.

The quantities of the various feeds used were obtained from actual weights made by the field agent on his regular monthly visit to each farm. Purchased concentrates were charged at the price paid and home-grown grains at the market price less cost of marketing. The various salable roughages were charged at the market price on the farm, and noncommercial roughages at a price commensurate with their value as compared with marketable roughage.

PASTURE.

On some of the farms, the pastures had been seeded and fenced, and received considerable care. On other farms the herds were allowed to graze over the "Piney-Woods" pasture, which consisted of cut-over timber lands. This land produced some grass and considerable underbrush. Practically the only charge for the "Piney-Woods" pasture was the extra time for a man and horse to hunt the cows and drive them home. The pasture did not cost much and its value as a source of feed was low.

LABOR.

The average labor rate per hour was obtained by dividing the wages per month plus such extra consideration as board, house rent, milk, and fuel by the total number of hours available for work.

The hours available for work during the month were determined by the field man on his monthly visit to each farm. He noted the time work began in the morning and when it ceased in the evening, subtracting the time for meals and rest. The hours per day thus obtained were multiplied by the number of working days in that month, to which was added the work necessary on Sundays.

No charge for management was made, owing to the fact that no satisfactory basis could be found upon which to make such charge. The manager was allowed wages, for the time he worked as a regular hand, at the same rate per hour as it would have been necessary to pay if he had hired a man of equal skill to do the work. It should be remembered, therefore, that in any place where costs are shown the charge for skill of management has been omitted.

Table 6 shows that 75 per cent of the work in winter and 70.9 per cent of the work in summer was performed by men. The remainder of the work was performed by women or by boys and girls.

TABLE 6.—*Per cent of labor performed and hours per 100 pounds of milk for each class of help.*

Class of labor.	Winter.				Summer.			
	Distribution of work performed.			Labor for 100 pounds of milk.	Distribution of work performed.			Labor for 100 pounds of milk.
	1918-19	1919-20	Average.		1918	1919	Average.	
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Hours.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Hours.</i>
Managers.....	29.1	37.1	33.1	1.89	21.1	35.3	28.2	1.40
Hired men.....	37.4	46.3	41.9	2.39	41.3	44.1	42.7	2.12
Total man labor.....	66.5	83.4	75.0	4.28	62.4	79.4	70.9	3.52
Women.....	19.2	13.3	16.2	.94	17.3	18.7	18.0	.89
Boys and girls.....	14.3	3.3	8.8	.52	20.3	1.9	11.1	.55
Total.....	100.0	100.0	100.0	5.74	100.0	100.0	100.0	4.96

OTHER COSTS.

Other costs include such charges on buildings, equipment, and cattle as interest; depreciation, taxes, and repairs.

TABLE 7.—*Percentage relationship between buildings, equipment, and cattle costs and the capital invested.*

Item.	Buildings.	Equipment.	Cattle.	Total.
Capital invested.....	\$27,924.52	\$12,107.90	\$63,658.00	\$103,690.42
Capital invested per cow.....	31.28	13.57	71.31	116.16
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Interest.....	8.4	8.8	8.0	
Depreciation.....	6.3	30.4	8.1	
Taxes.....	.7		1.0	
Insurance.....	.1			
Upkeep and repairs.....	6.0	10.5		
Milking-machine repairs.....		.4		
Total.....	21.5	50.1	17.1	22.1

Table 7 represents the average relationship as it was found in the dairies studied. It does not necessarily represent the standard nor the most economical relationship between the factors.

The figures at the foot of each of the four columns show the percentage relationship of the cost to the capital invested as recorded at the heads of the columns.

BUILDINGS.

At the beginning of the work the buildings and silos were inventoried at their replacement value in normal times. After the first inventory, the subsequent values were determined by deducting from the value at the beginning of the year the amount of depreciation during the year. The depreciation per year was based upon the remaining years of usefulness of the buildings. Insurance charges were taken from the receipts of the insurance companies.

The cost for upkeep and repairs was obtained by keeping a record of actual expenditures made during the year. Necessary expenses, such as roofing and painting, which do not occur every year, were determined by prorating the costs over the length of life of the roof or the duration of the paint and charging only the yearly share of such expense.

EQUIPMENT.

Because of rapid wear and breakage farm tools and equipment have a short life, which explains the depreciation charge of 30.4 per cent. The cost of such supplies as washing powder, coal oil, and gasoline amounted to \$1.99 per cow per year.

CATTLE.

Milk produced by a purebred cow has no greater value than that produced by a grade cow. Raising purebred cattle is a separate business involving larger investment and operating costs and resulting in larger credits for calves dropped. To avoid the effect of the purebred business upon the requirements for producing milk, the purebred cows found in the herds, which consisted mainly of grade cows, were given values equal to those of grade cows of corresponding production. Purebred calves were likewise credited as grade calves from grade cows of corresponding production.

At the beginning and end of the year each cow was given an inventory value. The first value was based on the price for which the owner thought he could replace her. In order to avoid the influence of market conditions her subsequent value remained the same unless her owner thought that she had become a better or a poorer cow. However, it was impossible in many cases to prevent the market condition from influencing the judgment of the owner.

To obtain the depreciation on cattle, the value of every cow that entered the herds during the year was added to the inventory at the beginning of the year; from this result was subtracted the total value of the cows at the end of the year plus the price received for cows sold during the year.

Taxes chargeable to the dairy were taken from the official tax records.

PERCENTAGE COMPARISON OF FACTORS INVOLVED.

A comparison of the cost of producing milk in winter and in summer, and the items chiefly responsible for this variation are presented in Table 8.

The totals of the cost of production in the first two columns show that it cost 4.6 per cent more to produce milk in winter than it did in summer. The feed, bedding, and pasture cost was 5.2 per cent

more in winter but the labor cost was slightly less in winter than in summer.

The credit for calves and manure amounted to 7.2 per cent of the total annual gross cost. On the farms studied the credits for calves and manure failed by 15.2 per cent of the gross cost ($18.2 + 4.2 - 7.2$) to equal the "other costs," including depreciation on the herds.

TABLE 8.—*Per cent of total annual gross costs represented by feed, labor, and other costs and credits for calves and manure, by seasons.*

Item.	Winter.	Summer.	Entire year.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Feed and bedding cost.....	27.9	21.4	49.3
Pasture cost.....	1.4	2.7	4.1
Feed, bedding, and pasture cost.....	29.3	24.1	53.4
Labor cost.....	11.7	12.5	24.2
Other costs except herd inventory variation.....	9.2	9.0	18.2
Total cost except herd inventory variation.....	50.2	45.6	95.8
Depreciation on herd.....	2.1	2.1	4.2
Total cost of production.....	52.3	47.7	100.0
Credits for calves and manure:			
Calves.....	0.8	0.9	1.7
Manure.....	2.9	2.6	5.5
	3.7	3.5	7.2

AVERAGE COSTS COMPARED WITH BULK-LINE COSTS.

Table 9 shows the difference between the average and the bulk-line costs. Considerable latitude is allowable in selecting the bulk line, but it is usually selected to include from 80 to 90 per cent of the total volume of milk produced. Thus the bulk-line cost indicates the cost at or below which the greater volume of the milk is produced. Only the dairymen having extremely high costs will have costs above the bulk-line cost. This table shows the figures for each separate herd, and the relative position of the average cost and the average income in the scale of herd costs.

During the first winter 84 per cent of the milk was produced at a cost of \$5.67 or less per 100 pounds. The average cost of producing milk for this same period was \$4.97 and the average income received from milk was \$4.34 for each 100 pounds sold.

During the first summer the bulk-line cost might be placed at either \$3.37 or \$3.44, since the table shows that 86 per cent of the total volume of milk was produced at or below \$3.37 and 90.4 per cent at or below \$3.44. The average income from milk sold during this season was \$3.67 per 100 pounds.

The bulk-line cost for the second winter might be placed at \$6.59 or \$6.74, since these costs correspond to 81.4 per cent and 87.2 per cent, respectively, of the total volume.

TABLE 9.—*Net cost, quantity, and per cent of milk produced by each herd, during two winters and two summers.*

Winter 1918-19.				Winter 1919-20.			
Cost per 100 pounds.	Milk produced.			Cost per 100 pounds.	Milk produced.		
	Quantity.	Per cent of total.	Cumulative per cent.		Quantity.	Per cent of total.	Cumulative per cent.
	<i>Pounds.</i>	<i>Per cent.</i>	<i>Per cent.</i>		<i>Pounds.</i>	<i>Per cent.</i>	<i>Per cent.</i>
\$3.65	25,469	4.7	4.7	\$3.22	48,270	8.4	8.4
3.94	41,231	7.6	12.3	3.74	31,911	5.5	13.9
4.28	32,805	16.0	18.3	4.62	26,030	4.5	18.4
4.31	55,007	10.1	28.4	4.75	27,879	4.8	23.2
1 4.34	-----	-----	-----	1 4.94	-----	-----	-----
4.53	28,114	5.1	33.5	4.98	29,695	5.2	28.4
4.62	21,027	3.9	37.4	5.29	20,366	3.5	31.9
4.63	42,384	7.8	45.2	5.39	32,758	5.7	37.6
1 4.97	-----	-----	-----	5.43	31,970	5.5	43.1
4.98	45,478	8.3	53.5	5.46	41,967	7.3	50.4
4.99	25,188	4.6	58.1	5.57	23,593	4.1	54.5
5.02	55,427	10.2	68.3	2 5.57	-----	-----	-----
5.34	40,610	7.5	75.8	5.87	21,289	3.7	58.2
5.47	20,624	3.8	79.6	6.14	13,563	2.4	60.6
5.67	23,754	4.4	84.0	6.20	26,277	4.6	65.2
6.26	53,063	9.7	93.7	6.49	43,810	7.6	72.8
6.30	7,647	1.4	95.1	6.59	49,597	8.6	81.4
6.55	26,950	4.9	100.0	6.74	33,134	5.8	87.2
				6.77	23,893	4.1	91.3
				6.90	36,338	6.3	97.6
				6.96	13,608	2.4	100.0
	544,778	100.0	-----		575,948	100.0	-----
Summer 1918.				Summer 1919.			
\$2.07	35,700	4.4	4.4	\$2.02	60,814	7.0	7.0
2.08	86,067	10.7	15.1	2.06	58,227	6.8	13.8
2.42	78,539	9.7	24.8	2.39	42,348	4.9	18.7
2.45	40,436	5.0	29.8	2.93	47,959	5.6	24.3
2.62	45,251		35.4	3.08	29,126	3.4	27.7
2.82	31,840	3.9	39.3	3.13	36,180	4.2	31.9
2.88	40,251	5.0	44.3	3.25	63,617	7.4	39.3
1 2.91	-----	-----	-----	3.38	32,357	3.8	43.1
3.02	36,369	4.5	48.8	3.49	79,340	9.2	52.3
3.03	52,455	6.5	55.3	2 3.51	-----	-----	-----
3.04	37,039	4.6	59.9	3.62	43,543	5.0	57.3
3.13	76,424	9.5	69.3	3.80	58,674	6.8	64.1
3.36	70,210	8.7	78.0	3.82	45,902	5.3	69.4
3.37	64,837	8.0	86.0	3.99	61,723	7.2	76.6
3.44	35,066	4.3	90.4	1 4.14	-----	-----	-----
3.47	30,209	3.7	94.1	4.32	36,643	4.2	80.8
3.65	32,043	4.0	98.1	4.56	19,376	2.2	83.0
1 3.87	-----	-----	-----	4.60	65,992	7.7	90.7
4.47	15,563	1.9	100.0	4.91	16,106	1.9	92.6
				4.93	32,188	3.7	96.3
				4.98	31,838	3.7	100.0
	808,299	100.0	-----		861,953	100.0	-----

¹ Average income.² Average cost.

The high price of feed made the cost of production much higher than it would have been under normal conditions. A study of the figures also shows that the cost of production will continue to be high so long as the average production of milk per cow is so low.

Feeding the same quantity of grain to cows bred for higher production would possibly double the quantity of milk produced and thereby increase the profits to the dairymen. The cattle tick has been eradicated from a large part of the section, and dairymen would find the milk business more profitable if they would keep better cows and feed them in accordance with their productive ability.

A study of the records also shows that dairymen could save grain by feeding more legume hay and succulent roughage. On many farms a larger quantity of manure could be saved, which when spread on the land would not only help to prevent the rains from gullyng the soil, but would tend to produce larger crops.

MONTHLY DISTRIBUTION OF FACTORS IN MILK PRODUCTION.

How did the income from milk and the quantity sold and used each season compare with each other? How did the income and feed cost by seasons compare? These questions can be answered by referring to Table 10.

TABLE 10.—*Distribution, by months, of milk prices, milk sold and used, feed cost, and labor required.*

YEAR 1918-19.

Month and season.	Income per 100 pounds of milk.	Income from milk sold and used.	Milk sold and used.	Feed, pasture, and bedding cost.	Pasture and bedding cost minus manure and bedding credits.	Human labor.		Horse labor.	
						Per 100 pounds of milk.	Per cow.	Per 100 pounds of milk.	Per cow.
		<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Hours.</i>	<i>Hours.</i>	<i>Hours.</i>	<i>Hours.</i>
October.....	\$4.37	7.9	7.4	7.2	6.1	6.3	13.7	0.9	2.0
November.....	4.36	7.0	6.5	8.4	7.4	6.2	12.1	.8	1.5
December.....	4.30	6.0	5.7	9.0	8.0	7.4	13.3	1.1	2.0
January.....	4.63	6.8	5.9	11.7	10.7	6.6	12.5	1.0	1.9
February.....	4.60	6.3	5.6	10.6	9.5	6.2	10.8	1.0	1.7
March.....	3.98	9.1	9.2	8.5	7.4	5.3	14.9	.9	2.5
Winter.....	4.34	43.1	40.3	55.4	49.1	6.2	12.9	.9	1.9
April.....	4.07	9.1	9.0	7.2	6.2	5.3	14.7	.8	2.2
May.....	3.92	10.0	10.3	7.3	6.4	4.9	15.2	.6	1.9
June.....	3.88	9.6	10.0	7.0	6.1	4.8	14.3	.6	1.7
July.....	3.74	9.6	10.4	7.8	6.9	5.5	15.6	.6	1.7
August.....	3.83	10.1	10.8	7.8	6.8	5.0	14.8	.6	1.8
September.....	3.78	8.5	9.2	7.5	6.6	5.6	15.7	.7	2.0
Summer.....	3.87	56.9	59.7	44.6	39.0	5.2	15.1	.6	1.9
Year.....	4.06	100.0	100.0	100.0	88.2	5.7	14.0	.8	1.9

YEAR 1919-20.

October.....	5.07	7.8	6.8	6.8	5.9	5.5	12.6	0.9	2.0
November.....	5.21	7.3	6.2	7.7	6.8	5.9	12.7	.9	1.9
December.....	5.07	6.9	6.1	9.6	8.8	5.5	11.6	1.0	2.0
January.....	4.95	7.0	6.3	10.8	10.0	5.1	11.3	.7	1.7
February.....	4.81	7.0	6.5	9.3	8.5	4.8	11.4	.7	1.8
March.....	4.64	8.4	8.2	10.2	9.2	5.0	13.3	.7	2.0
Winter.....	4.94	44.4	40.1	54.4	49.1	5.3	12.2	.8	1.9
April.....	4.22	9.2	9.8	7.8	7.1	4.7	14.2	.7	2.1
May.....	4.13	10.2	11.0	7.6	6.8	4.4	14.8	.7	2.3
June.....	4.03	9.6	10.6	7.2	6.4	4.5	14.1	.6	2.0
July.....	4.17	10.0	10.7	7.7	7.0	4.7	15.9	.7	2.3
August.....	4.18	9.0	9.6	7.9	7.1	5.1	15.0	.8	2.3
September.....	4.13	7.6	8.2	7.4	6.7	5.1	13.8	.7	2.0
Summer.....	4.13	55.6	59.9	45.6	41.1	4.8	14.6	.7	2.2
Year.....	4.46	100.0	100.0	100.0	90.2	5.0	13.4	.8	2.0

During the first year, 56.9 per cent of the yearly income from milk, 59.7 per cent of the yearly quantity of milk, and 44.6 per cent of the yearly cost of feed, bedding, and pasture, came during the summer season. This shows a difference of 2.8 between percentage of the income from milk and the volume of milk. The difference between the income from milk and the feed, bedding, and pasture cost amounted to 12.3 per cent.

SUMMARY.

Feed, bedding, and pasture cost amounted to 53.4 per cent of the total cost of production. Labor made up 24.2 per cent; and other costs, including depreciation on herd, amounted to 22.4 per cent. (See Table 8.)

The requirements for producing 100 pounds of milk in winter were: Concentrates, 72.4 pounds; hauling and grinding grain, \$0.095; dry roughage, 38.3 pounds; silage and other succulent roughage, 78.4 pounds; pasture, \$0.155; bedding, 0.3 of a pound; human labor, 5.8 hours; horse labor, 0.9 of an hour; total other costs, \$1.220. (See Table 1.) Credits for winter production other than milk: Manure, 127.7 pounds; calves, 0.033 of one calf. (See Tables 3 and 4.)

In summer the requirements were: Concentrates, 52.5 pounds; hauling and grinding grain, \$0.050; dry roughage, 1.9 pounds; silage and other succulent roughage, 8.1 pounds; pasture, \$0.197; human labor, 5 hours; horse labor, 0.7 of an hour; total other costs, \$0.803. Credits other than milk: Manure, 78.2 pounds; calves, 0.023 of one calf.

To keep a cow one year it required: Concentrates, 1,893 pounds; hauling and grinding grain, \$2.14; dry roughage, 538 pounds; silage and other succulent roughage, 1,171 pounds; bedding, 4 pounds; pasture, \$5.58; human labor, 164.5 hours; horse labor, 23.7 hours; total other costs, \$30.40. (See Table 2.) Credits other than milk: Calves, 0.8 of one calf; manure, 3,060 pounds.

To keep a bull one year requires: Grain, 1,202 pounds; hauling grain, \$1.07; dry roughage, 779 pounds; silage and other succulent roughage, 1,126 pounds; bedding, 4 pounds; pasture, \$4.66; human labor, 33.6 hours; total other costs, \$23.40; credit for appreciation or increase in value of bulls, \$20.89. (See Table 5.)

The dairy work was distributed as follows: Winter, men, 75 per cent; women, 16.2 per cent; boys and girls, 8.8 per cent; Summer, men, 70.9 per cent; women, 18 per cent; boys and girls, 11.1 per cent. (See Table 6.)

Interest, depreciation, taxes, insurance, and upkeep and repairs amounted to 22.1 per cent of the capital invested. (See Table 7.)

During each of the two winters the average income received from milk was 63 cents per 100 pounds below the average cost of production,

but during the first summer season the income received from milk was 96 cents above, and during the second summer 63 cents above the average cost of production. (See Table 9.)

Receipts for milk during the two winters were 43.1 per cent and 44.4 per cent of the receipts for the respective years. The net feed, pasture, and bedding cost was 49.1 per cent of the yearly net feed, pasture, and bedding cost for both the first and second winters. (See Table 10.)

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WM. A. TAYLOR, Chief



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August 17, 1921

A STUDY OF THE FACTORS AFFECTING TEMPERATURE CHANGES IN THE CONTAINER DURING THE CANNING OF FRUITS AND VEGETABLES.¹

By C. A. MAGOON and C. W. CULPEPPER, *Office of Horticultural and Pomological Investigations.*

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BASIS OF THE STUDY.

Successful preservation of foods by canning is due primarily to the fact that in the processing, or cooking, the bacteria and other microorganisms which cause spoilage are destroyed. Since the elimination of these microorganisms is dependent upon the use of heat as a sterilizing agent, it becomes of paramount importance to know just what temperatures and processing periods will destroy them. If uniformly good results are to be expected, a sufficient degree of heat must penetrate to all parts of the can or jar, and must

¹The manuscript of this bulletin was submitted for publication on February 27, 1920; circumstances of an incidental character interfered with its early issue.

be maintained long enough to render all microorganisms harmless. Before an accurate judgment as to the proper cooking period can be formed it is necessary to know how long a time is required for the food at the center of the container to reach the temperature of the retort or water bath in which it is being processed.

In the work here reported upon attention has been centered upon these time-temperature relations, and the purpose has been to bring to light underlying principles rather than to lay down definite rules of procedure, for specific recommendations should be preceded by carefully demonstrated facts.

The diagrams and other data presented are based upon the results of more than 600 tests made during the year 1919. All vegetables used were grown especially for this work on the experimental farm at Arlington, Va., and these, together with such fruits as were used, were handled fresh from the fields. In the details of preparation of these materials for the tests, no attempt was made to follow any particular set of rules hitherto laid down. Rather, an endeavor was made to illustrate average conditions, and the results of this experimentation are offered in the hope that they may be of service to other workers in this field.

REVIEW OF THE LITERATURE.

Attention was first called to the importance of the rate of heat penetration into cans of food material during processing by Prescott and Underwood (12, 7)² in 1898. In a study of the cause of souring in canned corn these authors went thoroughly into the bacteriology of the problem and isolated and studied the causal organisms found. A long series of experiments was undertaken involving more than 400 tests, in which, by the use of maximum thermometers sealed into the cans, the length of time required for the temperature at the center of the cans of corn to reach that of the retort was determined. Their results showed that, whatever the temperature of processing, the center of the cans of corn reached the temperature of the retort in approximately the same time. This observation has been made by later investigators and accords with the findings reported in this work.

These workers found that in processing corn at 118.8° C. for 1 hour 55 minutes were required for the center of the 2-pound can to reach the temperature of the retort, and they concluded that in processing for 1 hour the maximum temperature was maintained for only 5 minutes. They failed to take into consideration, however, the fact that in substances of heavy consistency, such as corn, the temperature is maintained for a considerable time at or very close to the temperature of the retort after removal from it to the air.

² Serial numbers in parentheses refer to "Literature cited" at the end of this bulletin.

In the various discussions of their work the fact was also pointed out that the quantity of liquor added to corn affects the rate at which heat penetrates into it.

Duckwall (9) in 1905 reported similar experiments with peas. He also found that, regardless of the temperature of processing, the temperature in the can reached that of the retort in the same length of time.

In the same year Belser (1), working upon the spoilage of canned foods, also reported upon studies of the time-temperature relations in the cans. He worked with peas, beans, mixed vegetables, carrots, tomato puree, comfrey, spinach, sauerkraut, cherries, and apple pulp. Maximum temperatures during the processing were obtained by the use of maximum thermometers, and numerous tables of results were given. These show, as might be expected, considerable variations in the temperatures reached by the different foods when handled under identical conditions. Belser pointed out the great importance of knowing the speed at which the heat penetrates to the center of the cans and performed several experiments with peas and beans to determine this. The method of preparation of material, the nature of the containers, and the details of his work were such as to make direct comparisons with American work impossible.

Haselhoff and Bredemann (10) in their report of investigations upon the decomposition of canned foods (1906) referred briefly to an apparently unpublished work of Huber in which attention was called to the fact that during the processing of certain food products the temperature inside the containers often did not reach that of the bath or retort in which they were processed.

Kochs and Weinhausen (11) carried on experiments (1906-7) with cabbage, carrots, asparagus, apple sauce, and peas. The methods employed correspond closely to those of Belser (1), and their results are not comparable with the findings of American workers. They pointed out that the rate of heat penetration is dependent upon the firmness of the pack and the proportion of liquid present. They worked also with glass and stoneware containers.

Bitting (2), in 1912, described two methods for the determination of the rate of heat penetration in cans of food. One method made use of long-stemmed thermometers held with the bulb at the center of the cans by means of a special device whereby direct reading of the temperature was made possible. The second method made use of thermocouples. For the higher temperature chlorid baths were used. Bitting pointed out that in substances having plenty of free liquid the heat passed in much more rapidly than in substances of heavy consistency and with less liquid. The advantages of agitation in shortening the cooking period were emphasized. No experimental data were given, however.

Zavalla (14), in 1916, published tables of experiments with cherries, apricots, peaches, and pears. He found the time required for the temperature to reach 212° F. at the center of the can processed in boiling water to vary with the different fruits and explained his findings as due to the difference in their heat conduction. He also stated that the concentration of the sirup seemed to exert a definite action upon the rapidity with which the heat penetrated to the center of the can. His conclusions agree with the results of the present work, but the tables given are not sufficiently clear to make direct comparisons possible.

Bitting and Bitting (4), using both thermometers and thermocouples, made numerous tests with various fruits and vegetables (1917). They worked out experimentally the effect of agitation upon the rate of heat penetration, and found that about 12 revolutions per minute gave the most satisfactory results in getting the heat to the center of the cans without injuring delicate fruits and berries. Numerous diagrams were given, showing the results of processing various substances with the cans held stationary and also rolled. These investigators stated that the minimum time was required to bring the temperature of the can to that of the surrounding bath in those foods in which the proportion of liquid allowed free convection and that mashed sweet potatoes required about the maximum. Furthermore, they found that in sweet potatoes the temperature at the center of the can rarely reaches to within 10 degrees centigrade of that of the retort or bath during the ordinary processing. Their results are entirely in accord with the conclusions drawn from the present work.

Denton (8) in 1918 reported the results of two tests with carrots in which the influence of closeness of pack on heat penetration was considered.

During the same year (1918) Bovie and Bronfenbrenner (5) described a thermoelectric apparatus for measuring the rate of heat penetration in foods during the canning process. The apparatus allowed the determination of the temperature at various parts of the can at any time during the processing by means of thermocouples. Measurements closer than 1° C. were not attempted, however, and the "constant" junction was placed in the autoclave close to the test can. Inasmuch as 15 minutes were required to obtain an equilibrium of pressure and therefore temperature, the "constant" junction did not become constant until 15 minutes after the can was placed in the retort.

While this apparatus would be satisfactory, perhaps, for substances like baked beans and sweet potatoes, it would be entirely unsuited for the determination of temperature changes in cans of such products as string beans and peas, in which the temperature in

the can attains or approaches closely that of the retort in less than 15 minutes. The prime advantage of the apparatus as described by these authors is that it allows the determination of the temperatures at various parts of the can at any time, thus giving a true idea of the rate of heat flow within the material itself. It is obvious, however, that the readings obtained under the conditions described are no more accurate than may be obtained by the direct reading of the mercury thermometer.

Castle (6) in 1919 called attention to the fact that the depth of the water bath about the jars directly affects the rate of change of temperature at the center of the containers, the shallower the bath the slower the rate of change. She also pointed out that in the intermittent process the first cooking may so compact the material that the heat penetrates more slowly in the second and third heatings. This was found to be true for leafy vegetables. No differences were obtained in the rate of change of temperature in blanched and unblanched string beans, and she erroneously concluded that blanching does not permit closer packing of this product.

Thompson (13) in 1919 published a preliminary report upon a large amount of valuable work dealing with temperature-time relations in various fruits and vegetables during processing, in which he made use of thermocouples. From these tests he developed mathematical formulas the object of which was to make possible the calculation of the temperature at the center of the can at any time during the processing, starting at any initial temperature.

Such formulas would be of great value if they could be made applicable to the handling of all food substances canned. In using such formulas, however, it is necessary to assume that all heat transferred is by conduction or else that any convection is very local. This would make the method inapplicable, apparently, for determining temperature changes in cans of substances such as string beans and peas, in which there is free convection, and would limit its usefulness to the canning of substances of heavy consistency, such as corn and squash. Inasmuch as the use of these formulas depends upon a constant factor, k (which in itself varies with different methods of processing, different containers, different kinds of food materials, differences in packs, and in some cases differences in varieties, stages of maturity, and other factors), it would seem that the establishment of the necessary constants would be very difficult and would in itself necessitate determinations which would give directly the original time-temperature facts desired. Furthermore, in certain substances the heat is carried inward during the first part of the processing period by convection, and in the latter part almost entirely by conduction. In other cases there is a change in the material in the can during processing resulting in the reverse of this, the heat passing

in at first by conduction and later by convection. Any formulas which take into consideration such factors as these must be very complex, indeed, and their application would be difficult and of doubtful value. This investigator may be able to overcome some of these difficulties in further work.

METHODS AND APPARATUS.

As has been pointed out, the earlier work upon the time-temperature relations in foods during canning made use of maximum thermometers, which were sealed into the material in the cans. While the information obtained in this way is valuable so far as it goes, for practical purposes and for the carrying out of careful scientific investigations the use of the maximum thermometer is out of the question. In the first place, for one experiment, which may require from one to many hours to complete, only one temperature reading can be obtained. In an experiment of this sort nothing is known of the exact length of time required for the material at the center of the can to reach the recorded temperature or of the length of time the temperature may have remained at that point. Furthermore, it is necessary to carry out many tests in order to record even a partial story of the time-temperature relations in a single can of material. To make studies of this kind of the most value, it is important to know not only what is the highest point reached, but also something of the rate of rise in temperature before that point is reached, and especially for how long it remains at or above the pasteurizing or sterilizing temperature during the processing.

To overcome the disadvantages of the maximum thermometer, thermocouples have been used in more recent investigations. These enable the worker to record the entire story of the temperature changes in any part of the can if desired, and when properly standardized they are highly accurate. The principal drawback in their use is the complexity of the equipment, which requires considerable technical skill to operate properly and the fact that the equipment is not available for many who would care to carry on studies in this field. Furthermore, thermocouples must be confined primarily to laboratory investigations, as they are unsuited to practical routine work.

With these facts in mind an endeavor was made to devise an apparatus which would be inexpensive to install, simple and easy to use, and at the same time sufficiently accurate for the determination of temperature changes under various conditions of processing. A standard method of determining temperature is by the use of the mercury thermometer, and it should be acceptable for this work, provided it is suitably constructed, properly calibrated, held securely,

and so placed as to make direct reading possible at all times during the processing. It is recognized, of course, that the mercury thermometer is subject to small inaccuracies, but when it is properly constructed and standardized these are too small to be of practical importance in work of this sort. In the work here reported special long-stemmed thermometers were employed which were calibrated for 6-inch immersion and graduated to read from -10° to $+150^{\circ}$ on the centigrade scale. When tested these thermometers showed a lag of only 15 seconds in passing from 0° to 100° —a lag even less than that of the thermocouple used by Thompson (13).

The use of long-stemmed thermometers for time-temperature studies is, of course, not new. Bitting (2) and others have employed them for experiments made when processing in the water and chlorid baths, but their use for tests carried on heretofore in the steam retort has not been found feasible. The difficulties have been successfully overcome, and the apparatus here described and illustrated shows how the temperature at the center of the can may be determined at all times, whether the processing is being done in the water bath or in the steam retort.

THE STEAM RETORT.

The steam retort used in these experiments was constructed from a piece of 8-inch water pipe 14 inches long, fitted at one end with a blind flange, which serves as the base of the retort, and at the other with a removable blind-flange cover. By means of $\frac{3}{4}$ -inch wrought-iron handles and hinged clamp bolts the cover may be placed in position and securely clamped down in a very few seconds. Steam from a boiler large enough to furnish an ample supply of steam at any pressure desired enters by way of a $\frac{1}{2}$ -inch pipe inserted in the side of the retort a few inches above the base, and an exhaust of the same size is provided in the bottom. A carefully tested and standardized pressure gauge is also attached.

In the cover a pet cock allows the rapid expulsion of air from the retort and also makes possible a continuous flow of steam about the test can during the processing. A 1-inch hole at the center of the cover is threaded to receive a special brass fitting to which the test can is attached. By means of a suitable gasket the joint is made steam tight, and with the brass fitting and the can in place the apparatus is ready for the insertion of the thermometer. The thermometer is passed through the brass fitting by way of a $\frac{3}{8}$ -inch hole until the bulb reaches the center of the test can, as determined by careful measuring beforehand, the funnel-shaped depression in the stem of the fitting provided with a suitable gasket, and the cap screwed down. The thermometer is thus held securely in position, and a steam-tight closure is easily made.

It will be seen, therefore, that the test can is firmly attached to the cover of the retort by means of the brass fitting, and the can may be placed in or removed from the retort in a very few seconds by simply putting on or taking off the cover. Owing to the small size of the retort, equilibrium at any steam pressure desired may be attained in

10 to 30 seconds.

The top of the mercury column is always in sight, and the temperature at the center of the container may be read directly at any time. Figure 1 shows the arrangement of the apparatus and the position of the test can in the retort.

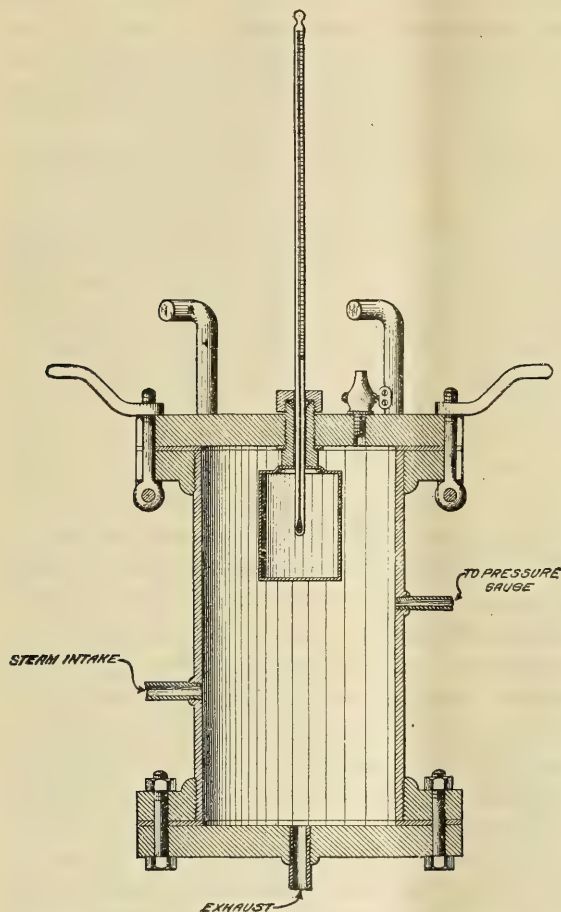


FIG. 1.—Apparatus designed for making time-temperature tests in canning food products, showing the position of the test can in the retort and the arrangement of the long-stemmed thermometer used in taking can temperatures.

THE BRASS FITTING.

The accompanying illustrations (fig. 2) show in detail the structure of the special fitting to which the can is attached for the test. Numerous modifications of this are possible, to suit all needs. The original form is shown at A. The threaded stem screws into the cover of the retort until the hexagonal shoulder presses upon the gasket and forms a

steam-tight joint with the retort cover. The threaded portion below the shoulder screws into the hole of the ordinary maximum thermometer test can in common use. With suitable gaskets air-tight joints are made, and the can may be attached or removed as desired. Cans of this type were used largely in these investigations. The $\frac{3}{8}$ -inch hole through which the thermometer is passed is reamed out

at the upper end to form a funnel-shaped depression to allow suitable packing, and the cap screws down to hold this tightly about the thermometer and make the seal perfect. In practice, this fitting is rarely removed from the retort cover, the can being unscrewed from beneath and the thermometer removed by unscrewing the cap.

It will be seen that this apparatus is as well suited for use with thermocouples as with thermometers.

A modification of *A* is shown at *B*, differing from it in that the fitting may be soldered directly to an ordinary hole-and-cap can.

For work with glass jars, those of the Mason screw-top type were used. These were attached to the fitting *A* (fig. 2) by removing the

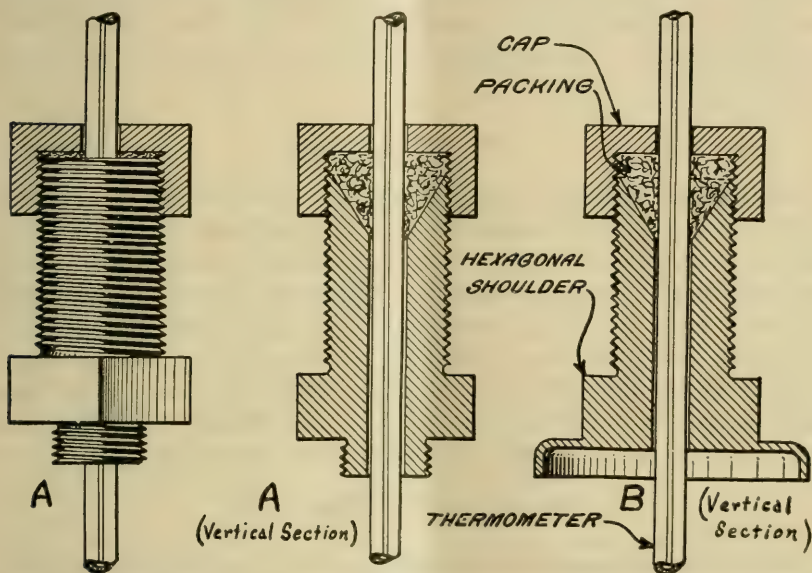


FIG. 2.—Details of the special fitting to which the can is attached for the test: *A*, The original form; *B*, a modification of *A*, differing from it in that the fitting may be soldered directly to an ordinary hole-and-cap can.

porcelain in the top, cutting a hole in the metal large enough to receive the portion of the fitting below the shoulder, and securing it firmly to the fitting by means of a suitable gasket and nut. The jar could then be placed in position for the test by simply screwing it into the top.

This apparatus as described may be constructed in any well-equipped machine shop at small expense. It is easy to operate, requires no special training for carrying out the tests beyond that possessed by anyone familiar with canning operations, and is sufficiently accurate for all practical needs. Tests made by its use have been carefully checked with thermocouples, and the differences observed in the results have been too small to be of practical significance. Any-

one, therefore, desiring to undertake time-temperature studies with canned foods need not hesitate to make use of this or a similar device.

THERMOCOUPLES.

The thermocouples used were constructed of copper and constantan wires by Dr. R. B. Harvey, of the Office of Plant Physiological and Fermentation Investigations, to whom the writers are greatly indebted for assistance in installing and standardizing the thermo-electrical equipment. The constant junction was located in an ice bath maintained at 0° C. by means of a thermos bottle filled with an ice and water mixture, and the variable junction was placed in the center of the container of material under test. The potential was measured with a potentiometer of recognized standard and a reflection type of galvanometer.

THE WATER BATH.

In all time-temperature experiments conducted at 100° C., a water bath was used. This consisted of a wooden tank 18 by 18 by 30 inches lined with galvanized iron and heated by means of a steam coil constructed from $\frac{3}{4}$ -inch pipe. The water was maintained at a constant level and kept vigorously boiling throughout the tests. Owing to the large volume of water in the bath, there was no cessation of boiling when the cans and jars were introduced. The temperature was therefore always 100° C., a condition which often does not obtain when small kettles or pots are used for the purpose.

PRELIMINARY EXPERIMENTS.

To obtain a thorough understanding of the factors influencing temperature changes in the can during the processing period and the subsequent cooling it was considered advisable to make some preliminary experiments which would serve as a basis for comparison. In these experiments distilled water, brines of various concentrations, and solutions of sugar and starch were treated as here described. The processing was done in the water bath at 100° C., and in the case of distilled water also in the retort at 109°, 116°, and 121° C.

DISTILLED WATER.

The first of these experiments was carried out with distilled water, using No. 2, No. 3, and No. 10 tin cans and pint and quart glass jars. In the case of the tin cans the water was filled to within one-fourth of an inch of the top and the device for holding the thermometer soldered to the can, making a steam-tight joint. In the glass a steam-

tight closure could not be made, owing to the inability of the glass to stand steam pressure.

Figure 3 shows the curves representing the temperature changes during the processing period and also the cooling in air and in water. These represent the averages of six tests for the rise in temperature during processing, but the cooling in water and in air are the averages of only three tests. The temperatures of the air and of the water in the different cooling tests varied somewhat, so that the curves are not absolutely uniform. The initial temperature was 20°C . The temperature of the water in which the cooling was done varied between 15° and 18°C . It is seen that the change in temperature at the center of the can is exceedingly rapid when the can

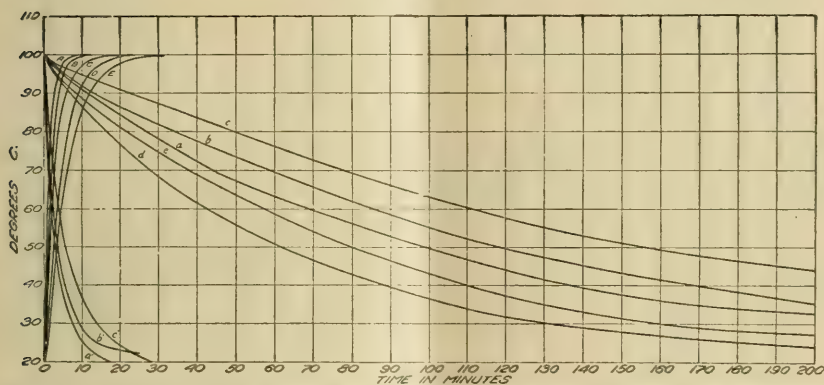


FIG. 3.—Time-temperature relations for distilled water when processed in various containers at 100°C . The curves representing rise in temperature during processing and the fall in temperature during cooling in water were plotted from readings made at intervals of 30 seconds; curves representing cooling in air, from readings at intervals of 5 to 10 minutes. Rise in temperature: A, in No. 2 tin cans; B, in No. 3 tin cans; C, in No. 10 tin cans; D, in pint glass jars; E, in quart jars. Cans cooled in water: a', No. 2 at 17°C ; b', No. 3 at 16°C ; c', No. 10 at $16\frac{1}{2}^{\circ}\text{C}$. Cooled in air: a, No. 2 cans at 17° to 20°C ; b, No. 3 cans at 16° to 20°C ; c, No. 10 cans at 16° to 18°C ; d, pint glass jars at 16° to 18°C ; e, quart glass jars at 18° to 20°C .

is plunged into the water bath at 100°C . In the No. 2 tin can the temperature of the bath is approached in about eight minutes. It is also noted that the No. 3 can is only slightly slower than the No. 2, requiring only two or three minutes longer to attain the temperature of the bath. The No. 10 tin can is somewhat slower than the No. 3, but even here the temperature at the center approaches that of the retort in 15 minutes. The temperature changes in the glass containers are very much slower than in the tin, requiring about 20 minutes for the temperature of the center of the pint jar to approach that of the water bath, and about 27 minutes for the quart jar to reach the same temperature. There is thus a very marked retardation in the glass. When the tin containers are removed from the boiling water bath and placed in water at 17°C , there is a very

sudden drop in the temperature at the center of the can. It falls to 30° in a very few minutes, the rate of cooling being only slightly slower than the rate of rise in temperature. As will be seen, the cooling in air is very slow when contrasted with the cooling in water. No cooling tests of glass in water, of course, could be made. In these tests in the cooling in air the glass cooled considerably faster than the tin. The diameter of the No. 2 tin can is less than that of the quart glass jar, yet the quart jar cools faster. This may have been caused in part by leakage around the cover of the jar, since a steam-tight closure was not possible, but it must be due largely to

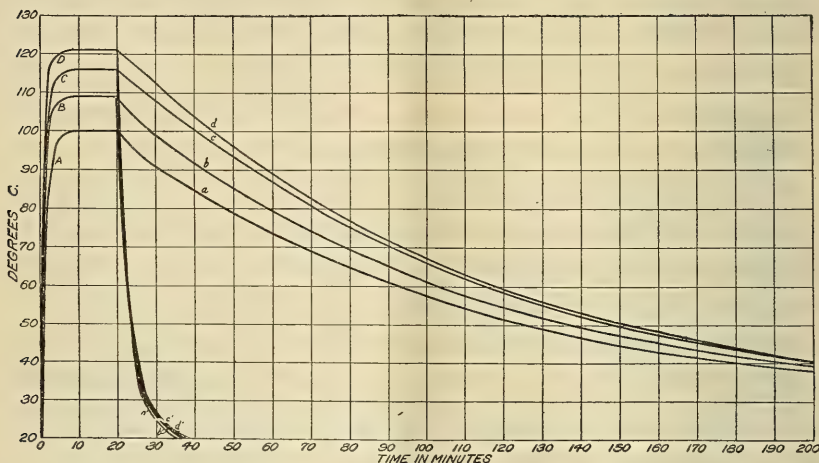


FIG. 4.—Time-temperature relations for distilled water when processed in No. 2 tin cans at 100°, 109°, 116°, and 121° C. and also when cooled in air and in water. The curves representing the rise in temperature during processing and the fall in temperature during cooling in water were plotted from readings made at intervals of 30 seconds; curves representing cooling in air, from readings made at intervals of 5 to 10 minutes. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C. Fall when cooled: a', From 100° C. in water at 17° C.; b', from 109° C. in water at 15° C.; c', from 116° C. in water at 16° C.; d', from 121° C. in water at 16° C.; a, from 100° C. in air at 17° to 20° C.; b, from 109° C. in air at 20° to 24° C.; c, from 116° C. in air at 25° C.; d, from 121° C. in air at 25° C.

the fact that glass radiates heat faster than tin. The rate of cooling in tin is in the order of the diameter of the cans, the No. 10 being slowest, the No. 3 next, and the No. 2 fastest. The pint glass jar is faster than the quart glass jar or the No. 2 tin can. The temperature of the room was not constant, varying between 16° and 20° C. The length of time necessary for any container to reach any specific temperature is shown by the curves.

In figures 4 to 7 are shown the curves representing the temperature changes at the center of the various cans of distilled water when processed at 100°, 109°, 116°, and 121° C. Since a steam-tight closure could not be made in the glass, any temperature above 100°

fell to 100° C. as rapidly as the temperature of the retort was lowered. The temperature at the center of the glass container was thus

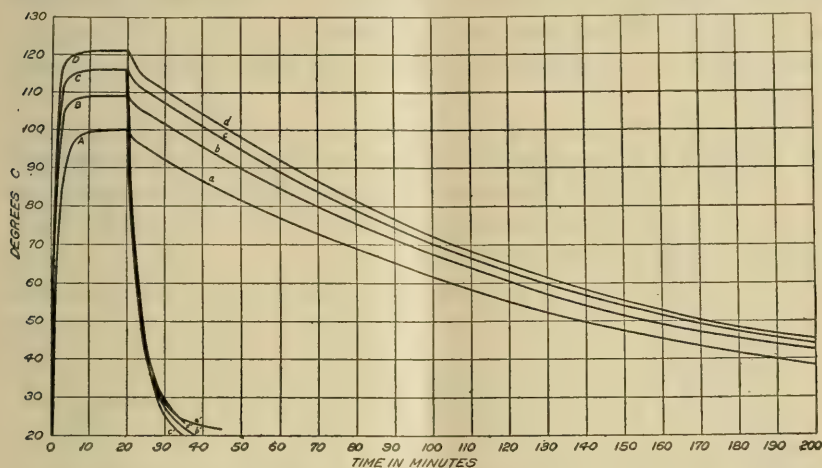


FIG. 5.—Time-temperature relations for distilled water when processed in No. 3 tin cans at 100°, 109°, 116°, and 121° C. and also when cooled in water and in air. The curves representing the rise in temperature during processing and the fall in temperature during cooling in air were plotted from readings made at intervals of 30 seconds; curves representing cooling in water were plotted from readings at intervals of 5 to 10 minutes. Rise in temperature when processed: *A*, At 100° C.; *B*, at 109° C.; *C*, at 116° C.; *D*, at 121° C. Fall when cooled: *a'*, From 100° C. in water at 16° C.; *b'*, from 109° C. in water at 17° C.; *c'*, from 116° C. in water at 15° C.; *d'*, from 121° C. in water at 17° C.; *a*, from 100° C. in air at 16° C.; *b*, from 109° C. in air at 25° C.; *c*, from 116° C. in air at 25° C.; *d*, from 121° C. in air at 25° C.

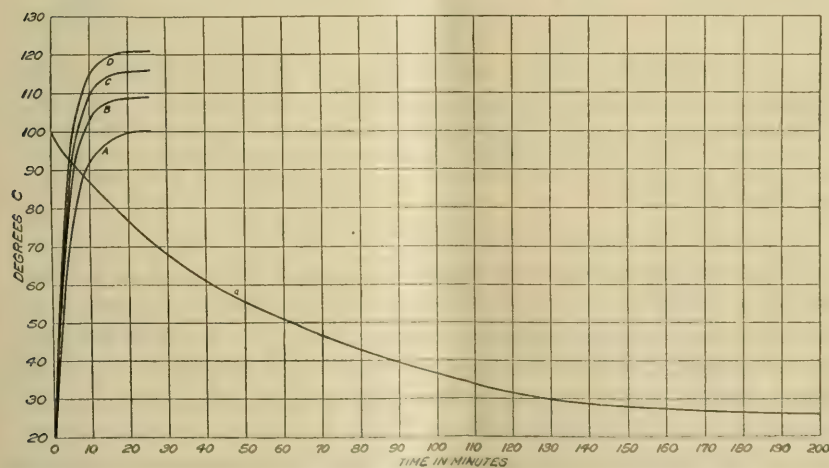


FIG. 6.—Time-temperature relations for distilled water when processed in pint glass jars at 100°, 109°, 116°, and 121° C. and also when cooled in air. The curves representing the rise in temperature during processing were plotted from readings made at intervals of 30 seconds; the curve representing cooling in air, from readings at intervals of 5 to 15 minutes. Rise in temperature when processed: *A*, At 100° C.; *B*, at 109° C.; *C*, at 116° C.; *D*, at 121° C. *a*, Fall from 100° C. when cooled in air at 15° to 20° C.

always at 100° C. when taken from the retort, and the cooling curve from this starting point is all that is given. In the case of the tin

cans processed at temperatures above 100° and cooled in air the sudden drop in temperature to 100° C. is not noted, the temperature falling gradually, and still more slowly as it approaches that of the room. These differences in cooling between the tin and glass containers are to be observed throughout the whole series of experiments.

One fact of importance shown by the curves is that the length of time required for the center of any can to attain the temperature of the bath or retort is approximately the same for all the temperatures here used, except that in some tests the boiling-water bath required a slightly longer time.

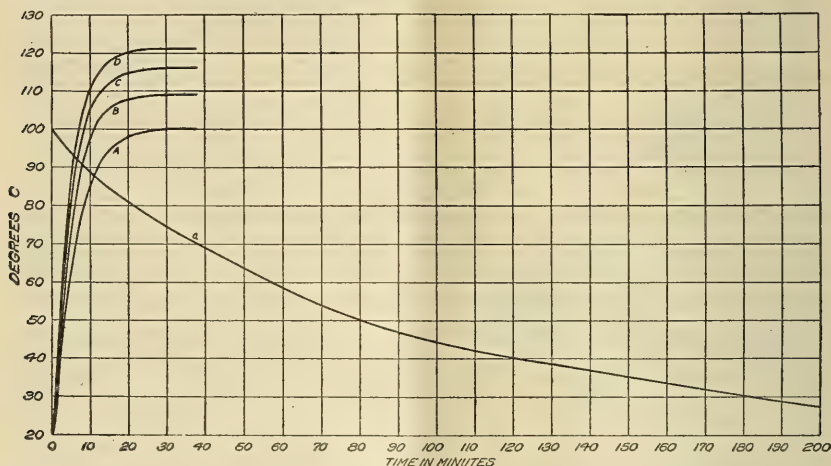


FIG. 7.—Time-temperature relations for distilled water when processed in quart glass jars at 100° , 109° , 116° , and 121° C. and also when cooled in air. The curves representing the rise in temperature during processing were plotted from readings made at intervals of 30 seconds; the curve representing cooling in air, from readings at intervals of 5 to 15 minutes. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C. a, Fall from 100° C. when cooled in air at 18° to 20° C.

BRINE.

To determine whether the addition of salt would have any direct influence upon the rate of change in temperature in the can, comparative tests were made, using distilled water, a 2 per cent brine, and a saturated brine. In figure 8 curves for saturated brine and distilled water show that the difference between distilled water and a saturated brine is insignificant. From the results of these experiments it is concluded that the proportion of salt commonly added to canned materials has no direct effect upon the rate of change of temperature at the center of the can.

SUGAR SOLUTIONS.

In order to get an idea of the possible effect that the addition of sugar to canned materials has upon the rate of change of temperature

in the can, comparative tests were made with 10 per cent, 30 per cent, and 60 per cent cane-sugar solutions. This series of tests was made with No. 3 tin cans in the boiling-water bath as the heating medium, and in circulating water at 17°C . as the medium for cooling. In each of the tests the cans were filled with the solution to within one-fourth of an inch of the top. The device for holding the thermometer was soldered in place and the thermometer so placed that the bulb was at the center of the can. The curves in figure 9 show the results obtained. The sugar solutions show no marked effect upon the rate of changes of temperature at the center of the can, where the concentration is 10 per cent or less. Even in a 60 per cent

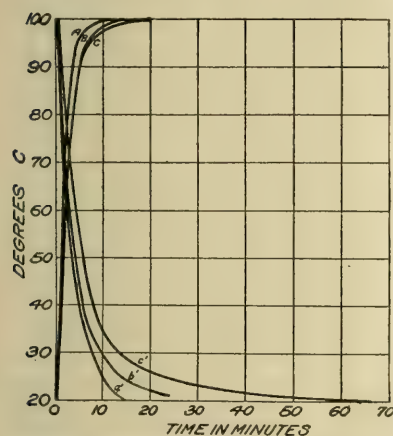


FIG. 9.—Time-temperature relations for 10 per cent, 30 per cent, and 60 per cent cane-sugar sirup when processed in No. 3 tin cans at 100°C . and also when cooled in water. These curves were plotted from temperature readings made at intervals of 1 minute. Rise in temperature: A, For 10 per cent sirup; B, for 30 per cent sirup; C, for 60 per cent sirup. Fall in temperature from 100° when cooled: a' , For 10 per cent sirup in water at $12\frac{1}{2}^{\circ}\text{C}$.; b' , for 30 per cent sirup in water at 17°C .; c' , for 60 per cent sirup in water at $15\frac{1}{2}^{\circ}\text{C}$.

of the can approaches that of the bath. It is known that the viscosity of the sugar solutions decreases as the temperature increases. It is this characteristic of sugar solutions that makes the temperature shown by the upward curves follow so closely that of distilled water.

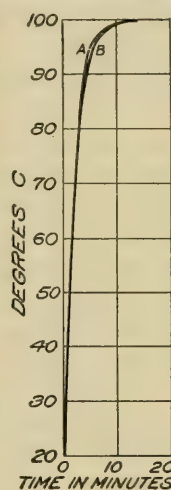


FIG. 8.—Time-temperature relations for distilled water and saturated brine when processed in No. 3 tin cans at 100°C . These curves were plotted from temperature readings made at intervals of 1 minute. A, Distilled water; B, saturated brine.

solution of sugar the effect is less marked than might be expected. The effect of the sugar solution upon the rate of change of temperature at the center of the can is due to the greater viscosity, which decreases

the rate of convection in the sugar solutions. The value of the force which tends to produce convection currents in the solution depends upon the steepness of the gradient between the temperature at the center of the can and the temperature at the margin of the solution, so that the force tending to produce convection currents becomes less and less as the temperature at the center

In the cooling off, however, there is an increase in the viscosity as the temperature falls. Also, as the temperature at the center of the can falls the temperature gradient between the center and the margin becomes flatter; hence, the force tending to cause convection becomes smaller and smaller, until finally the resistance due to viscosity is great enough to stop all convection, and the process becomes one of pure conduction, which is very much slower than convection. A pronounced flattening of the curve for 60 per cent sirup at about 30° C. is significant. The difference in viscosity at high and low temperatures makes the cooling curve much different from the upward curve. It appears from other tests that sugar solutions of 1 to 4 per cent when added to materials which are canned have very little effect upon the temperature change in the can, but concentration as high as 30 to 60 per cent will have considerable effect.

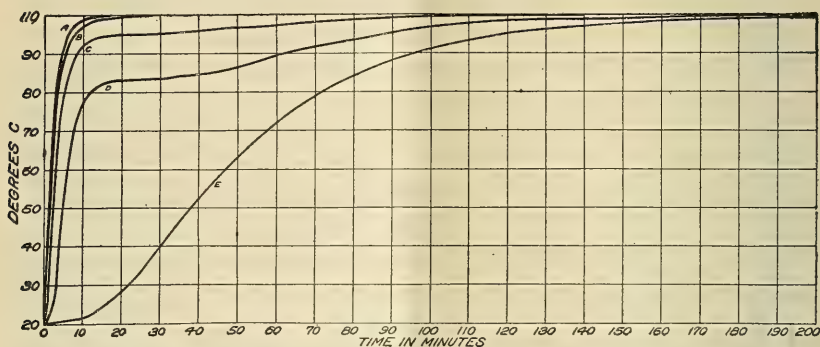


FIG. 10.—Time-temperature relations for 1 per cent, 2 per cent, 3 per cent, 4 per cent, and 5 per cent starch solutions when processed in No. 3 tin cans at 100° C. Curves A to D were plotted from temperature readings made at intervals of 1 minute and curve E from readings at intervals of 5 minutes. Rise in temperature: A, For 1 per cent solution; B, for 2 per cent solution; C, for 3 per cent solution; D, for 4 per cent solution; E, for 5 per cent solution.

STARCH SOLUTIONS.

To study further the effect of viscosity upon the rate of change of temperature in the can 1, 2, 3, 4, and 5 per cent starch solutions were tested in No. 3 tin cans in the boiling-water bath. No cooling tests were made. Carefully dried starch was weighed out and enough water added to make 1, 2, 3, 4, and 5 per cent solutions, respectively. The starch was gelatinized or brought into colloidal solution by heating on a steam bath for one hour, with constant stirring, and at the end of this time enough water was added to each lot to equal that lost by evaporation. Each lot appeared as a homogeneous grayish semi-transparent solution or paste. The lots were then cooled to 20° C., put into cans, and the thermometer-holding device soldered to the cans, as described under "Distilled water." Figure 10 shows the curves for these tests. Each curve represents the average of three tests.

It is seen from the curves that the rate of change of temperature at the center of the can in 1 per cent and 2 per cent starch solutions is not very different from that in distilled water, although there is a slight slowing down of the process. Curve *C*, figure 10, shows that the first part of the process of the 3 per cent solution is very rapid, but when the center of the can reaches about 92° C. there is a very marked slowing down of the rate of rise of temperature. Also in curve *D*, representing the 4 per cent starch solution, the first part of the process is very rapid, but when the temperature at the center of the can reaches about 80° C. there is a marked slowing down of its rate of rise. It stops almost entirely at about 83° and remains there for 10 to 15 minutes; then it begins to rise again, and gradually approaches the temperature of the bath. In the 5 per cent solution the process is slow from the beginning. It is clear that in the 1 per cent and 2 per cent solutions and in the first part of the processes of the 3 per cent and 4 per cent solutions convection is occurring, which explains the rapid rise in temperature at the center of the can. In the 5 per cent starch solution and in the last part of the process of the 3 per cent and 4 per cent solutions convection is not occurring to any great extent, and the heat reaches the center of the can by conduction only. In the 4 per cent solution the resistance due to the viscosity is not great enough to stop convection in the first part of the process. The force tending to produce convection becomes less and less as the temperature at the center of the solution approaches the temperature of the bath. Hence, convection continues in the solution until this force becomes so small that it fails to overcome the resistance due to viscosity, when the process of convection stops. Then the heat is conveyed only by conduction. This is probably what happened in the 3 per cent and 4 per cent starch solutions. Further change in the starch may have been a factor, as no tests were made to determine whether the starch solution had reached its maximum viscosity in the preliminary treatment. The curves for cooling in water would have been interesting, but unfortunately they were not made.

From these preliminary experiments it is concluded that the factors affecting the rate of change of temperature at the center of the can are the diameter of the container, the conductivity, thickness and radiative power of its walls, the temperature, conductivity, and mobility of its contents, and the temperature, conductivity, and movement of the medium surrounding it.

SINGLE-PERIOD PROCESSING.

With the facts of the preliminary experiments in mind, work was done with the various fruits and vegetables commonly canned, for

the purpose of determining to what extent these factors are of importance in actual canning practice. No attempt to follow exactly the procedure of any specific canning method was made, the object being to get at the underlying principles and fundamental factors of the time-temperature relations rather than to check up on prevailing methods.

STRING BEANS.

In the tests with string beans the Green Pod Stringless variety was used. The beans were gathered from the field, brought into the laboratory, washed, broken into pieces 1 to 1½ inches long, and then

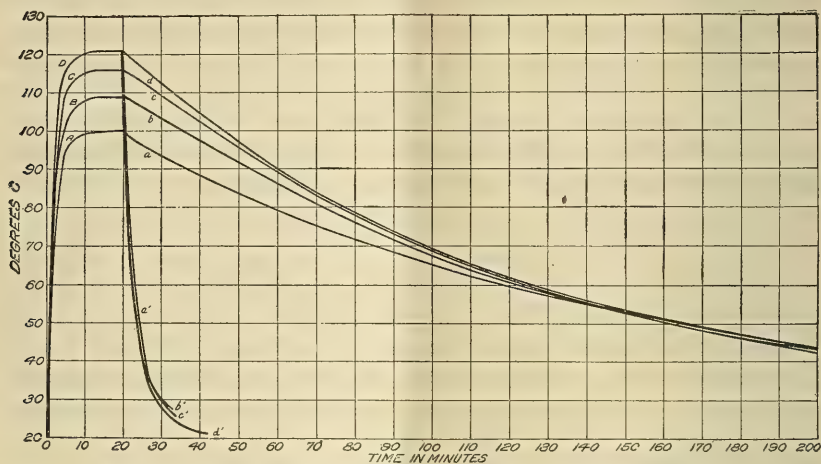


FIG. 11.—Time-temperature relations for string beans in 2 per cent brine when processed in No. 2 tin cans at 100°, 109°, 116°, and 121° C. and also when cooled in air and in water. The curves representing the rise in temperature during processing and the fall in temperature during cooling in water were plotted from readings made at intervals of ½ minute and 1 minute; those representing cooling in air, from readings at intervals of 5 to 10 minutes. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C. Fall in temperature when cooled: a', From 100° in water at 17° C.; b', from 109° in water at 17° C.; c', from 116° in water at 16½° C.; d', from 121° in water at 16½° C.; a, from 100° in air at 16° to 20° C.; b, from 109° in air at 19° to 22° C.; c, from 116° in air at 18° to 22° C.; d, from 121° in air at 19° to 22° C.

blanched for five minutes in boiling water. They were then allowed to cool to room temperature and placed in the cans. Two per cent brine was added to fill the interspaces. They were then processed at 100°, 109°, 116°, and 121° C. in No. 2 and No. 3 tin cans and in pint and quart glass jars. Figures 11 to 14 show the rise in temperature at the center of the various containers at the different processing temperatures.

It is observed that the rise of temperature is almost as rapid as that of distilled water alone. In 12 to 13 minutes the temperature at the center of the No. 2 tin can approaches or attains that of the retort or bath, and in 15 to 16 minutes the temperature of the No. 3 can

approaches that of the retort or bath. It requires about 30 minutes for the pint glass jar and about 35 minutes for the quart jar to reach

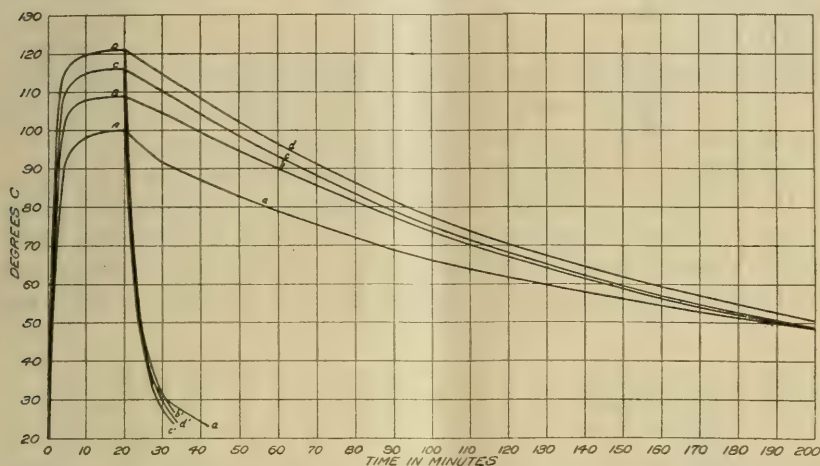


FIG. 12.—Time-temperature relations for string beans in 2 per cent brine when processed in No. 3 tin cans at 100°, 109°, 116°, and 121° C. and also when cooled in water and in air. The curves representing the rise in temperature during processing and the fall in temperature during cooling in water were plotted from readings made at intervals of $\frac{1}{2}$ minute and 1 minute; those representing fall in temperature during cooling in air, from readings at intervals of 5 to 10 minutes. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C. Fall in temperature when cooled: a', From 100° in water at 17° C.; b', from 109° in water at 16½° C.; c', from 116° in water at 16½° C.; d', from 121° in water at 16½° C.; a, from 100° in air at 25½° C.; b, from 109° in air at 25½° C.; c, from 116° in air at 25½° C.; d, from 121° in air at 22° to 26° C.

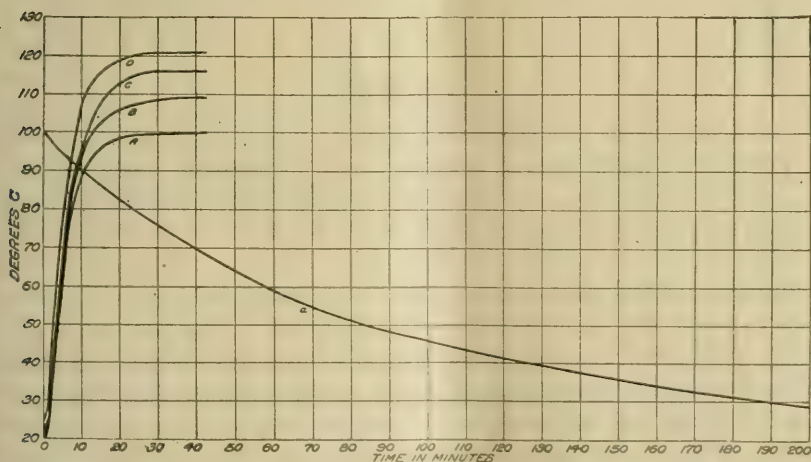


FIG. 13.—Time-temperature relations for string beans in 2 per cent brine when processed in pint glass jars at 100°, 109°, 116°, and 121° C. and also when cooled in air. The curves representing the rise in temperature during processing were plotted from readings made at intervals of 1 minute; the curve representing the cooling in air, from readings at intervals of 1 to 5 minutes. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C. a, Fall in temperature from 100° when cooled in air at 18° to 22° C.

the same temperature. It is evident that so far as time-temperature relations in the can are concerned there need be little difference in

the time for the processing of No. 2 and No. 3 tin cans of string beans. A somewhat longer time obviously should be recommended for the glass containers.

The temperature of the retort or bath is approached in practically the same time whether the processing temperature is 100°, 109°, 116°, or 121° C. Furthermore, the rise in temperature is so prompt that the stirring of the material, as in an agitating cooker, would be of no advantage in distributing the heat throughout the can.

It is to be understood that the temperature here measured is that of the liquid surrounding the beans. No record was obtained of the actual temperature in the beans themselves, but it would take at most only a few minutes longer for the heat to reach the center of the beans.

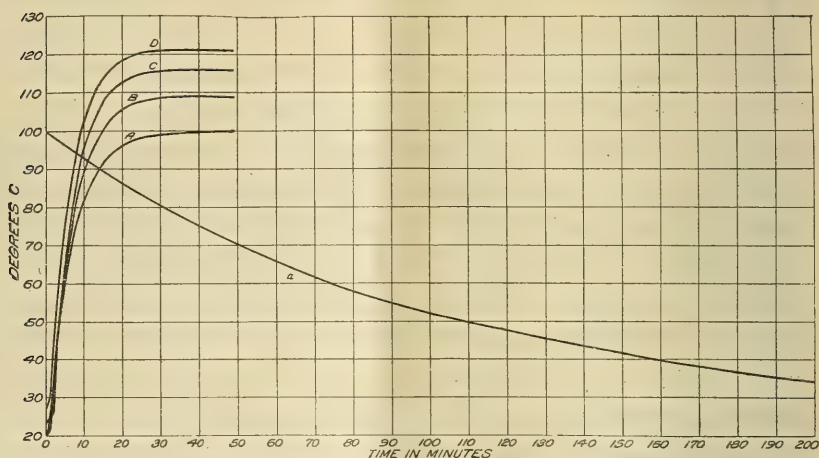


FIG. 14.—Time-temperature relations for string beans in 2 per cent brine when processed in quart glass jars at 100°, 109°, 116°, and 121° C. and also when cooled in air. The curves representing the rise in temperature during processing were plotted from readings made at intervals of 1 minute; the curve representing the cooling in air, from readings at intervals of 1 to 5 minutes. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C. a, Fall in temperature when cooled in air at 18° to 22° C.

Records of the temperature for the cooling, both in air and in water, were obtained. They are very similar to the cooling of distilled water, but are somewhat slower. Here, again, the very great difference in the rate of cooling in air and in water should be emphasized. When the containers were cooled in water the temperature fell to 30° C. in 10 minutes or less, while it took more than 3 hours to fall to the same temperature in air. In the glass, where a steam-tight closure could not be made, any temperature above 100° C. fell to 100° as rapidly in the container as in the retort, so that the temperature of the glass containers was always 100° when removed from the retort.

The temperature changes obtained in these tests are easily understood when the composition of the beans and the character of the pack are held in mind. The string beans contain only a small proportion of starch or other colloidal material which would readily go into solution or gelatinize, so the free liquid in the can is thus maintained throughout the processing period. This medium allows of convection, which rapidly distributes the heat throughout the can.

The surface tension between the liquid and the insoluble particles of material tends to obstruct convection currents, but since the pieces of material in this case are comparatively large the effect of the force of surface tension is correspondingly small. However, if the material is finely divided, as when it is ground in a food chopper, the surface tension is increased to such an extent as to cut down very greatly the rate of change of temperature.

Experiments were also made to determine whether the fullness of the pack has any effect upon the rate of change of temperature in the center of the can. In cans packed extra full and in cans lightly packed the differences were found to be so small as to be almost negligible. However, when the beans are thoroughly cooked they may be packed in the can so tightly as to make the interspaces filled with liquid more or less discontinuous, in which case there is a very marked slowing down of the temperature changes at the center of the can.

PEAS.

The variety of garden peas used in these tests was the Early Alaska. The peas were gathered from the field as used and brought into the laboratory and shelled by hand. In some of the tests the peas had somewhat passed the prime stage for canning. No attempt was made to grade them. They were blanched five minutes in the boiling-water bath and cooled to room temperature. The tin cans were filled to within one-fourth of an inch, and the glass jars to within half an inch of the top. Then enough 2 per cent brine was added to cover the peas. Each kind of container was processed at 100°, 109°, 116°, and 121° C. They were each cooled in air, and the tin cans were also cooled in water. Figure 15 shows the time-temperature record of a No. 2 can during the processing period at the various temperatures and also the cooling in air and in water. Figures 16, 17, and 18 show the temperature curves for the processing period in the No. 3 tin can and in the pint and quart glass jars, respectively.

It is observed from these curves that the temperature rises very rapidly. The No. 2 tin can approaches the temperature of the retort, or bath, in about 12 minutes, the No. 3 can in about 15 minutes, the pint glass jar in 30 minutes, and the quart jar in about 35 minutes.

The temperature changes are like those in string beans except that the time required to pass through the last degree is in most cases very much longer in the peas than in the string beans. Some viscous colloidal material cooks out into the free liquid during the processing period. The liquid seems to reach such viscosity as to stop convection currents at this point. The viscosity does not have to be very great in order to stop convection when the difference in temperatures at the center of the can and at the margin is one degree or less.

The difference in cooling in air and water is very marked, as is shown by the curve in figure 15. The curves for cooling in water show a marked slowing down of the fall of temperature when it

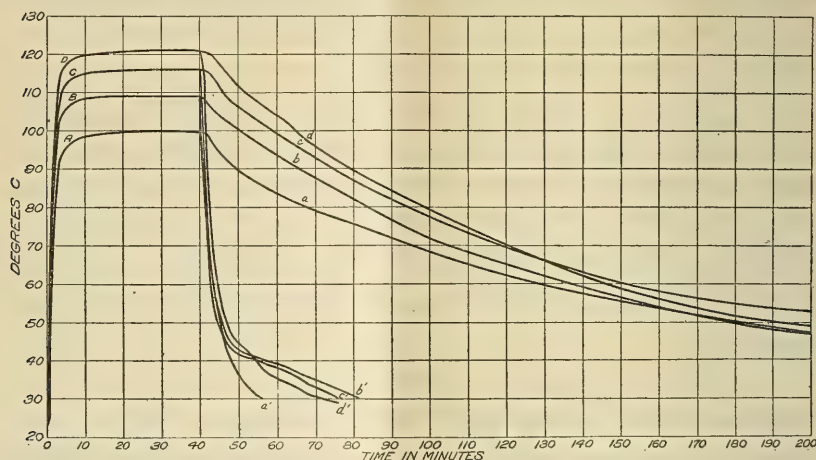


FIG. 15.—Time-temperature relations for peas in 2 per cent brine when processed in No. 2 tin cans at 100°, 109°, 116°, and 121° C. and also when cooled in water and in air. The curves representing the rise in temperature during processing and the fall in temperature during cooling in water were plotted from readings made at intervals of $\frac{1}{2}$ minute and 1 minute; those for cooling in air, from readings at intervals of 5 to 10 minutes. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C. Fall in temperature when cooled: a', From 100° in water at 20° C.; b', from 109° in water at 17° C.; c', from 116° in water at 20° C.; d', from 121° in water at 19° C.; a, from 100° in air at 26° to 30° C.; b, from 109° in air at 24° to 28° C.; c, from 116° in air at 24° to 28° C.; d, from 121° in air at 24° to 28° C.

reaches about 45° C., in those curves cooling from 121°, 116°, and 109° C. The one processed at 100° does not follow the same course as the other three. During the processing at the higher temperatures some soluble colloidal material was cooked out, which formed a solution so viscous as to stop convection at this point in the cooling. This does not occur in every case, and the rather mature condition of the samples used in these cases perhaps explains its occurrence here.

As in string beans, there need be little difference in the length of the processing period for No. 2 and No. 3 tin cans, as far as the rate of change of temperature at the center is concerned. The time for the processing of glass jars, however, should be longer.

Stirring the material during processing is of no advantage, because there is no difficulty in getting the heat to the center of the can.

It must be remembered also that the cooling is much faster in air than in the retort. If the cans are left packed in the retort to cool, the temperature may remain above 100°C . for 1 hour or longer. If the processing has been sufficient, a rapid cooling is of advantage,

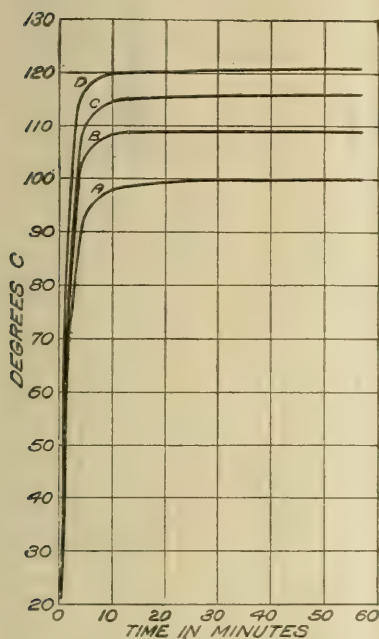


FIG. 16.—Time-temperature relations for peas in 2 per cent brine when processed in No. 3 tin cans at 100° , 109° , 116° , and 121°C . These curves were plotted from temperature readings at intervals of $\frac{1}{2}$ minute and 1 minute. Rise in temperature when processed: A, At 100°C .; B, at 109°C .; C, at 116°C .; D, at 121°C .

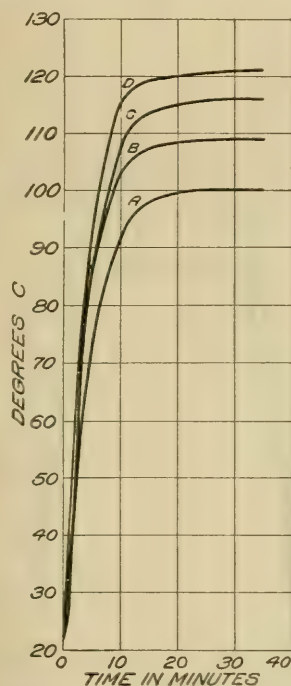


FIG. 17.—Time-temperature relations for peas in 2 per cent brine when processed in pint glass jars at 100° , 109° , 116° , and 121°C . These curves were plotted from temperature readings made at intervals of $\frac{1}{2}$ minute and 1 minute. Rise in temperature when processed: A, At 100°C .; B, at 109°C .; C, at 116°C .; D, at 121°C .

because the high temperature continues to alter the flavor and quality of the product.

Here, again, the temperature records shown are for the liquid filling the spaces between the peas, no attempt being made to measure the temperature within the peas themselves. This could have been done with suitable thermocouples, but it could not take more than a very few minutes for the heat to be conducted from the surrounding

liquid to the center of the peas. If the peas are fresh and sound the organisms to be destroyed would be on the surface and not in the center of the peas.

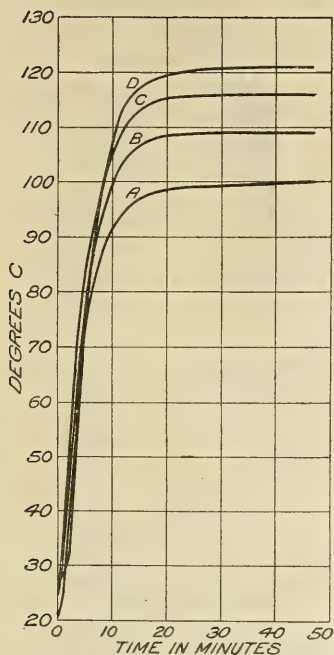


FIG. 18.—Time-temperature relations for peas in 2 per cent brine when processed in quart glass jars at 100°, 109°, 116°, and 121° C. These curves were plotted from temperature readings made at intervals of $\frac{1}{2}$ minute and 1 minute. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C.

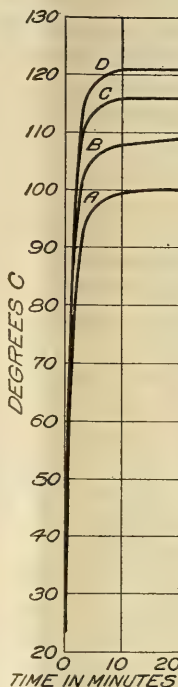


FIG. 19.—Time-temperature relations for Lima beans in 2 per cent brine when processed in No. 2 tin cans at 100°, 109°, 116°, and 121° C. These curves were plotted from temperature readings made at intervals of $\frac{1}{2}$ minute and 1 minute. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C.

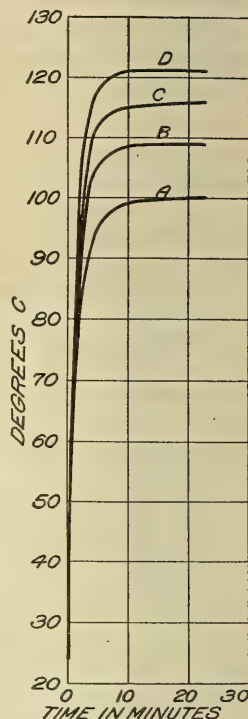


FIG. 20.—Time-temperature relations for Lima beans in 2 per cent brine when processed in No. 3 tin cans at 100°, 109°, 116°, and 121° C. These curves were plotted from temperature readings made at intervals of $\frac{1}{2}$ minute and 1 minute. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C.

LIMA BEANS.

The variety of Lima beans used in these tests was the Dwarf Garden King. The beans were full grown but not dry and were in prime condition for table use. They were gathered, brought into the laboratory, and shelled by hand. The shelled beans were washed and packed tightly into the cans without being blanched, and only enough

2 per cent brine added to cover the beans. They were processed in the same way as the string beans. The results are shown in figures 19 to 22.

It will be seen from these curves that the rate of temperature change in Lima beans does not differ essentially from that in string beans. The stirring of the material during processing is unnecessary. Cooling tests in water were not made, and the curves for cooling in

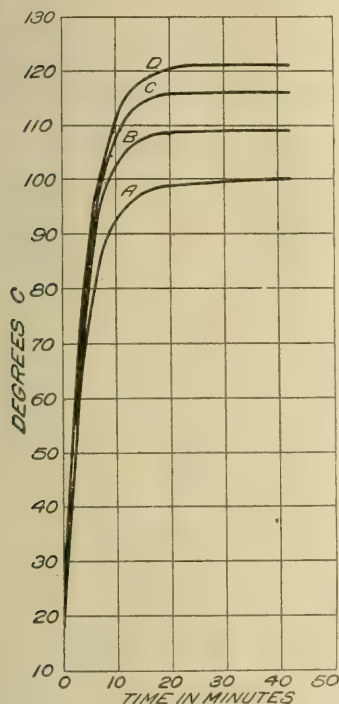


FIG. 21.—Time-temperature relations for Lima beans in 2 per cent brine when processed in pint glass jars at 100°, 109°, 116°, and 121° C. These curves were plotted from temperature readings made at intervals of $\frac{1}{2}$ minute and 1 minute. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C.

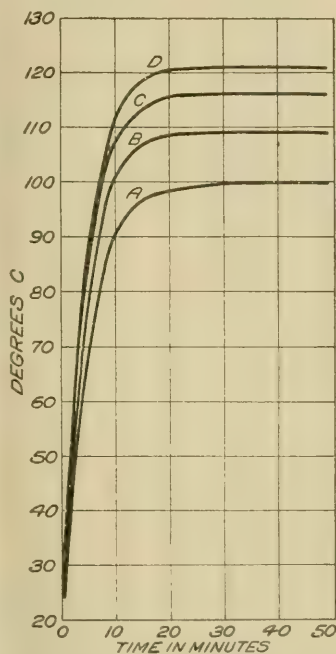


FIG. 22.—Time-temperature relations for Lima beans in 2 per cent brine when processed in quart glass jars at 100°, 109°, 116°, and 121° C. These curves were plotted from temperature readings made at intervals of $\frac{1}{2}$ minute and 1 minute. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C.

air, which were found to be very similar to those for string beans, are omitted, as they add nothing of value.

SOY BEANS.

The variety of soy beans used in these tests was the Easy Cook. The beans were gathered when most of the pods were beginning to turn yellow. They were brought into the laboratory, spread upon

trays, and steamed for 5 minutes to soften the hulls so that the shelling could be done more readily. The shelled beans were filled into the cans and enough 3 per cent brine was added to cover the beans. The usual tests in No. 2 and No. 3 tin cans and pint and quart glass jars at 100°, 109°, and 121° C. were carried out. No cooling in water was made. Figures 23 to 26 show the rise in temperature at the center of the cans for both tin and glass containers.

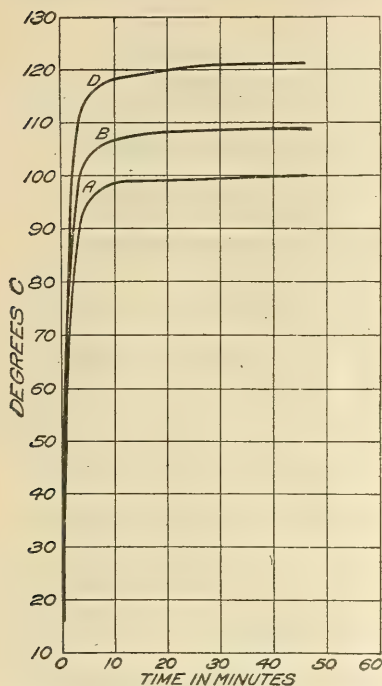


FIG. 23.—Time-temperature relations for soy beans (Easy Cook) in 3 per cent brine when processed in No. 2 tin cans at 100°, 109°, and 121° C. These curves were plotted from temperature readings made at intervals of $\frac{1}{2}$ minute and 1 minute. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; D, at 121° C.

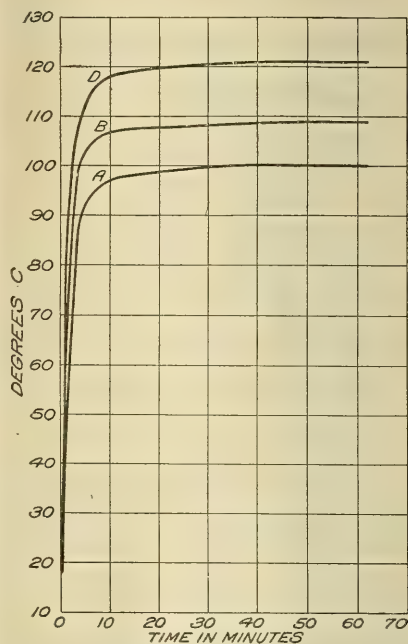


FIG. 24.—Time-temperature relations for soy beans (Easy Cook) in 3 per cent brine when processed in No. 3 tin cans at 100°, 109°, and 121° C. These curves were plotted from temperature readings made at intervals of $\frac{1}{2}$ minute and 1 minute. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; D, at 121° C.

The temperature rises very rapidly during the first part of the processing period. When it approaches to within 2 or 3 degrees of that of the retort, or bath, the rise in temperature is much slower than in the string beans. The soy beans contain a very soluble protein which quickly cooks out into the surrounding liquid; the viscosity of which soon becomes such as to stop all convection currents. The heat then passes inward by conduction, which is comparatively slow. The cooling in air is considerably slower than in string beans or peas. No cooling in water was made, but it would

very probably have been much slower than for string beans, for the cooking out of viscous colloidal substances greatly affects the rate of cooling.

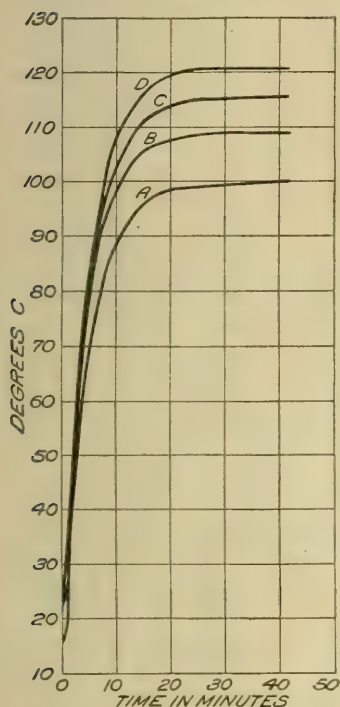


FIG. 25.—Time-temperature relations for soy beans (Easy Cook) in 3 per cent brine when processed in pint glass jars at 100°, 109°, 116°, and 121° C. These curves were plotted from temperature readings made at intervals of $\frac{1}{2}$ minute and 1 minute. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C.

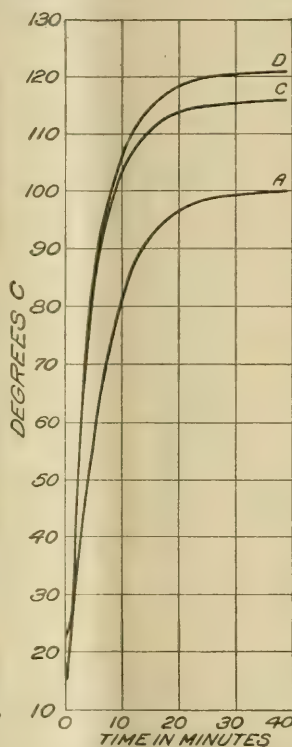


FIG. 26.—Time-temperature relations for soy beans (Easy Cook) in 3 per cent brine when processed in quart glass jars at 100°, 116°, and 121° C. These curves were plotted from temperature readings made at intervals of $\frac{1}{2}$ minute and 1 minute. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C.

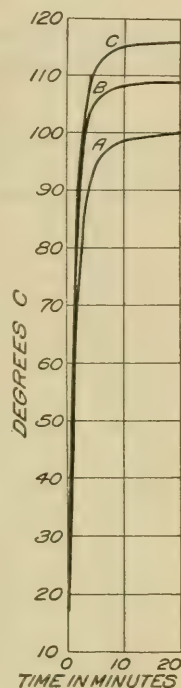


FIG. 27.—Time-temperature relations for asparagus in 2 per cent brine when processed in No. 2 tin cans at 100°, 109°, and 116° C. These curves were plotted from temperature readings made at intervals of $\frac{1}{2}$ minute and 1 minute. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.

The differences in No. 2 and No. 3 tin cans and pint and quart glass jars are the same as noted in string beans, and the same conclusions can be drawn as to the length of time for processing.

Experiments have shown that the readiness with which viscous materials cook out in soy beans varies considerably in the different varieties and with the different stages of maturity. Of the several varieties tested the Easy Cook is the softest and the cooking out is

greatest. Also the amount of soluble protein material which cooks out in processing seems to increase as the beans approach a mature or ripe stage.

ASPARAGUS.

Rather comprehensive studies were made with asparagus, which included experiments to show the effect of differences in the nature of

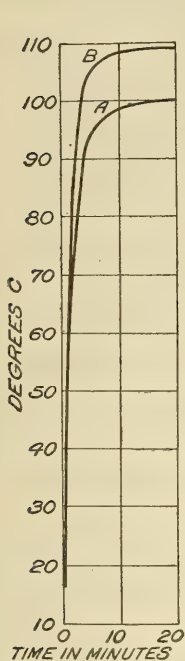


FIG. 28.—Time-temperature relations for asparagus in 2 per cent brine when processed in No. 3 tin cans at 100° and 109° C. These curves were plotted from temperature readings made at intervals of $\frac{1}{2}$ minute and 1 minute. Rise in temperature when processed: A, at 100° C.; B, at 109° C.

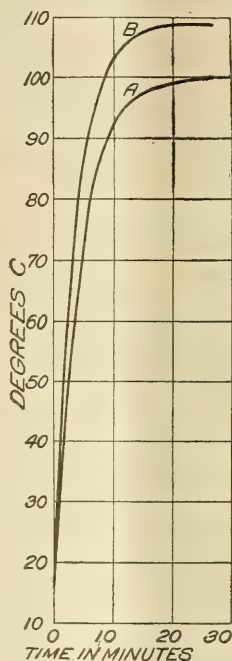


FIG. 29.—Time-temperature relations for asparagus in 2 per cent brine when processed in pint glass jars at 100° and 109° C. These curves were plotted from temperature readings made at intervals of $\frac{1}{2}$ minute and 1 minute. Rise in temperature when processed: A, At 100° C.; B, at 109° C.

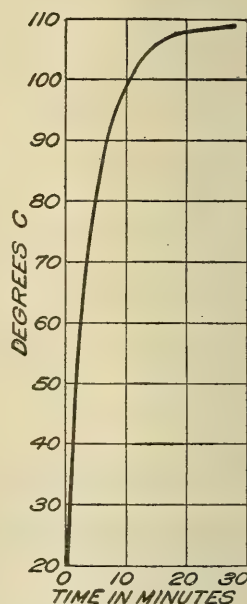


FIG. 30.—Time-temperature relations for asparagus in 2 per cent brine when processed in quart glass jars at 109° C. This curve was plotted from temperature readings made at intervals of 1 minute.

the pack and the comparative effects of water and of brine upon the rate of change of temperature. Tests relating to the rate of cooling both in air and in water under these different conditions were also made. No perceptible differences were observed when water and when brine were used, or when different kinds of packs, viz, whole tips or one-half inch pieces, were employed. One set of curves, there-

fore, illustrates what was obtained in each case. Figures 27 to 30 show the curves for asparagus prepared by washing, cutting the stalks into one-half inch pieces, and packing into the containers, after which 2 per cent brine was added to fill the interspaces.

It will be noted that the curves for asparagus do not differ essentially from those of string beans. The cooling in air and in water also gave curves entirely similar to those of string beans.

Asparagus does not contain any large amount of soluble colloidal materials to cook out and change the viscosity of the surrounding liquid to any great extent, although it easily collapses when it is cooked too long or at too high a temperature.

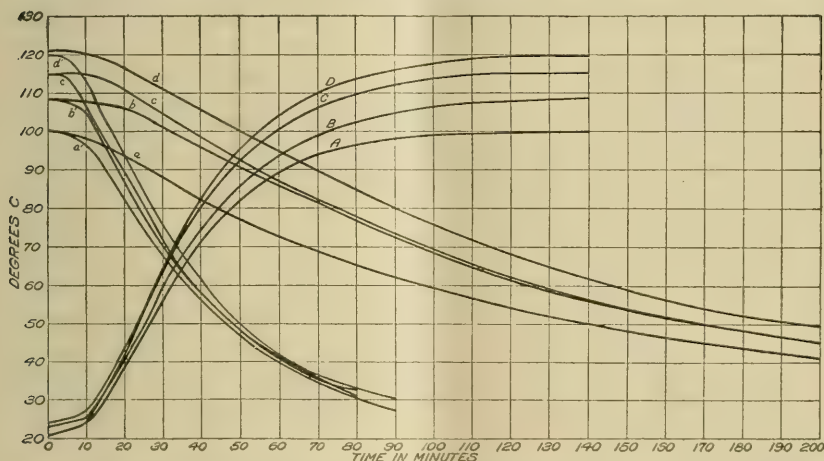


FIG. 31.—Time-temperature relations for sweet corn (Maine style) when processed in No. 2 tin cans at 100°, 109°, 116°, and 121° C. and also when cooled in air and in water. The curves representing the rise in temperature during processing and the fall in temperature during cooling in water were plotted from readings made at intervals of 5 minutes; those for cooling in air, at intervals of 5 to 10 minutes. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C. Fall in temperature when cooled: a', From 100° in water at 15° C.; b', from 109° in water at 22° C.; c', from 116° in water at 21° C.; d', from 121° in water at 18° C.; a, from 100° in air at 22° to 26° C.; b, from 109° in air at 25° to 28° C.; c, from 116° in air at 25° to 28° C.; d, from 121° in air at 25° to 28° C.

SWEET CORN.

The variety of corn used in these tests was Stowell's Evergreen. The corn was picked the same day that the test was made, and only ears that were in prime condition for canning were used. It was husked, the silks removed with a coarse brush, washed, and then cut off the cob "Maine style," i. e., about one-third of the grain was cut away with a sharp knife and then the rest scraped from the cob. A liquor of 2 per cent salt and 6 per cent sugar was prepared and added to the corn in the can to give the proportion of 5 parts of corn to 1 part of liquor. It was then processed in the various containers at the different temperatures, as in the previous experiments. Figures 31 to 34 show the results of these tests.

These curves indicate that the heat penetrates into the cans very slowly. It requires two hours to approach the temperature of the retort in a No. 2 tin can and nearly three hours to reach the same temperature in the No. 3 can. In one and one-half hours the pint glass jar approaches the temperature of the retort and in about two hours the same temperature is reached in the quart glass jar. It is very evident, therefore, that little convection is taking place. Convection is prevented in part by the finely divided condition of the corn, and further by the viscous condition of the liquor, which results from gelatinization of the starch. The differences in the rate of change of temperature between the No. 2 and No. 3 tin cans are very great, indicating the necessity of different processing periods.

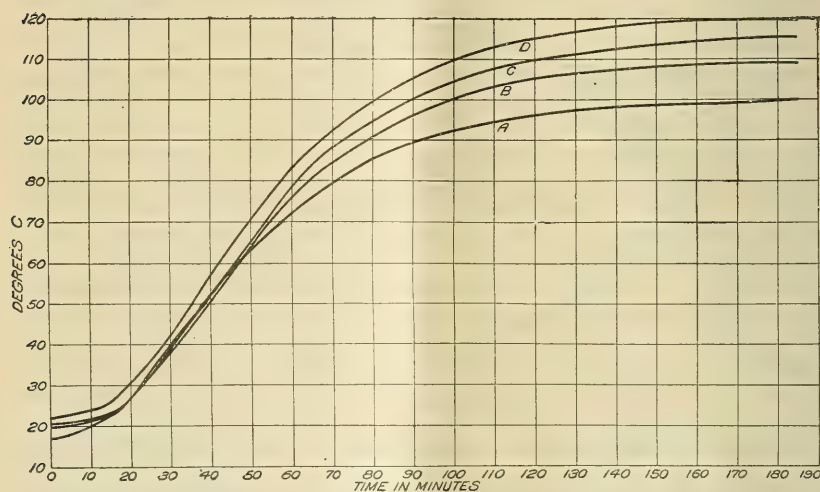


FIG. 32.—Time-temperature relations for sweet corn (Maine style) when processed in No. 3 tin cans at 100°, 109°, 116°, and 121° C. These curves were plotted from readings made at intervals of 5 minutes. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C.

The difficulty of getting the heat to the center of a No. 3 can and the quart glass jars is so great that it is advantageous to can sweet corn in No. 2 tin cans or in pint glass jars. It is to be noted that the low conductivity of the glass ceases to be a factor here, and the rate of change of temperature follows more nearly the order of the diameters of the containers, i. e., the pint glass jar is fastest, then the No. 2 tin can, the quart jar next, and the No. 3 can slowest. This order is quite different from that of string beans.

Stirring the material would very greatly aid in getting the heat to the center of the can for corn prepared in the Maine style, and for this reason agitating cookers might be especially advantageous for handling corn packed in this manner.

Figure 31 shows the record of cooling for a No. 2 tin can in air and in water. The cooling in air is considerably slower than that of string beans, but the differences are not so great as might be expected from the differences in the rise in temperature. The cooling in water, although very much faster than the cooling in air, is still very slow in comparison to the cooling of string beans in water. It requires about 1 hour and 20 minutes for the corn to fall to 30° C. in these tests, whereas string beans required only 10 to 15 minutes. These differences in the rate of cooling in air and in water. It required about tremely important when it is remembered that high temperatures seriously affect the appearance and flavor of the corn.

Attention is again called to the fact that when the steam is cut

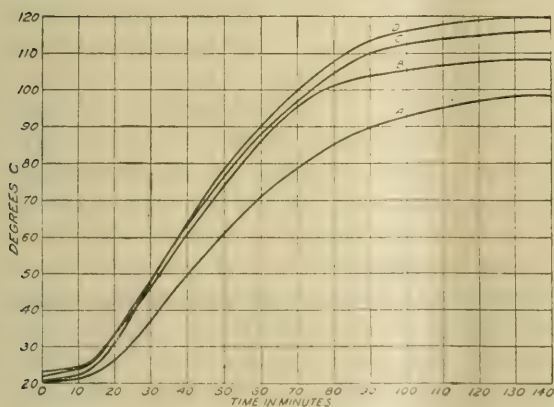


FIG. 34.—Time-temperature relations for sweet corn (Maine style) when processed in quart glass jars at 100°, 109°, 116°, and 121° C. These curves were plotted from temperature readings made at intervals of 5 minutes. Rise in temperature when processed: A, At 100° C. (the proportion of corn to liquor in this case, unfortunately, was less than in those processed at the higher temperatures); B, at 109° C.; C, at 116° C.; D, at 121° C.

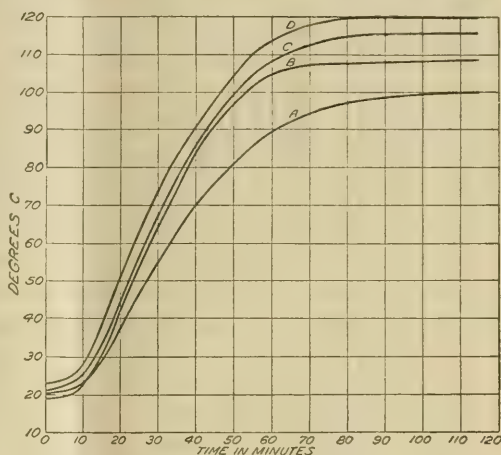


FIG. 33.—Time-temperature relations for sweet corn (Maine style) when processed in pint glass jars at 100°, 109°, 116°, and 121° C. These curves were plotted from temperature readings made at intervals of 5 minutes. Rise in temperature when processed: A, At 100° C. (the proportion of corn to liquor in this case, unfortunately, was less than in those processed at the higher temperatures); B, at 109° C.; C, at 116° C.; D, at 121° C.

off at the end of the processing period the temperature of the jars falls from any temperature above 100° to 100° C. as rapidly as the temperature in the retort. This is important, especially in substances like corn, as sterilizing temperatures are maintained for much shorter periods than in tightly sealed cans.

VARIETAL DIFFERENCES.

Other tests were made to determine

whether varietal differences in corn had any effect upon the rate of change of temperature at the center of the can. Comparison was made of White Dent field corn, Golden Bantam, Country Gentleman, Stowell's Evergreen, and Crosby's Early. No differences of importance were observed when these varieties were prepared in Maine style. Tests with corn at different stages of maturity were not made, although this would have been of interest, since the starch content is known to increase during the approach to maturity.

It is not probable, however, that the differences in maturity generally permissible in canning practice would have any effect.

MAINE STYLE AND MARYLAND STYLE COMPARED.

Having found that differences in the fineness of division of particles affects the rate of change of temperature, tests were made for the

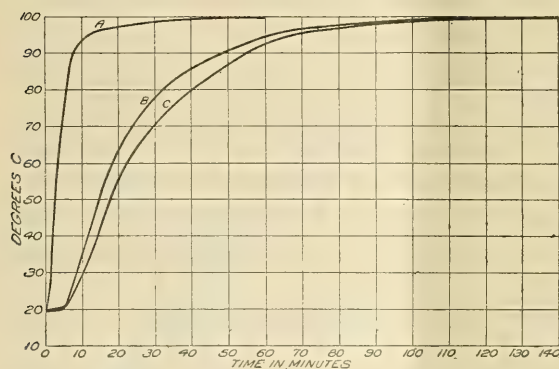


FIG. 35.—Time-temperature relations for sweet corn (Maine style and Maryland style) processed at 100° C. in No. 2 tin cans. These curves were plotted from temperature readings made at intervals of 5 minutes. Proportion of corn to liquor: A, Maryland style, 2.1:1; B, Maine style, 2.1:1; C, Maine style, 3.1:1.

cans were used, and the same proportion of corn and liquor (by weight) was used in each case. The proportion of corn to liquor was 2.1 to 1. The results when processed in the water bath at 100° C. are shown in figure 35.

A higher rate of change of temperature is noted in the Maryland style than in the Maine style, as the result of the greater freedom of movement of the liquor filling the interspaces. There was some convection in each case, but the results probably would have been entirely different if the proportion of water to corn had been other than that used in these tests. Such marked differences as are shown in these experiments should be borne in mind when processing periods are under consideration.

EFFECT OF DIFFERENT PROPORTIONS OF LIQUOR.

Tests were made to determine the effect of different proportions of corn to liquor upon the rate at which heat passes into the can. The

purpose of comparing the Maine style and Maryland style of packing. Stowell's Evergreen was the variety used for these tests. In the Maine style the corn was prepared as already described. In the Maryland style the corn was prepared by cutting the grains from the cob as nearly whole as possible, without scraping. No. 2 tin

variety used in these tests was Stowell's Evergreen. The corn was prepared in the Maine style, placed in No. 2 tin cans, and processed at 100° C. The proportions of corn to liquor used in these tests were 1 to 0, 1 to 1, 2 to 1, 3 to 1, 4 to 1, and 5 to 1. The results are shown in figure 36.

In the can having the proportion of 1 to 1 there is a very rapid rise in temperature, due largely to convection which occurs in the liquid. The last two or three degrees go very slowly, however, owing to gelatinization of the starch, which increases the viscosity to such an extent as to counteract the force, small at this point, tending to cause convection. In the can having the proportion of 2 to 1 there is a marked falling off in the rate throughout the curve. There is considerable convection here, but it is less pronounced and stops sooner than in cans having the proportion of 1 to 1. Likewise in the 4 to 1 and in the 5 to 1 there is a further falling off of the rate of temperature rise.

In these cans convection is further reduced and probably plays only a small part in the 5 to 1 cans. It is noted that the temperature at the center of the can approaches that of the bath more quickly in the case of the corn alone than in the proportion of 5 to 1, 4 to 1, or 3 to 1. This apparent inconsistency is easily understood when

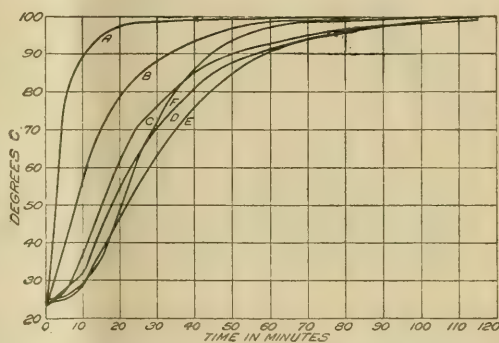


FIG. 36.—Time-temperature relations for sweet corn (Maine style) with different proportions of liquor processed in No. 2 tin cans at 100° C. These curves were plotted from temperature readings made at intervals of 5 minutes. Proportion of corn to liquor: A, 1 : 1; B, 2 : 1; C, 3 : 1; D, 4 : 1; E, 5 : 1; F, corn alone.

one realizes what is taking place in the four cans. In the can having the proportion of 5 to 1 there is little, if any, convection, for the going into solution of the starch forms a mass having so small an amount of free liquid that very little or no convection takes place. In the proportion of 4 to 1 some convection occurs, but it is checked early in the process by the same cause. The same in general is true in the case of 3 to 1, but more time is required to arrest the convection currents. In the corn alone there is no free liquor in which convection can take place, but there is a saturated air more or less continuous from the center to the outside of the material, which certainly allows some convection, thus accounting for the more rapid rise in the corn alone than in the 4 to 1 and the 5 to 1 cans. If the material in the can of corn alone had been packed down tightly the curve would have been considerably different.

PUMPKIN.

The Connecticut Pie pumpkin was used in the tests. The pumpkins were washed, split into halves, and the seeds removed. They

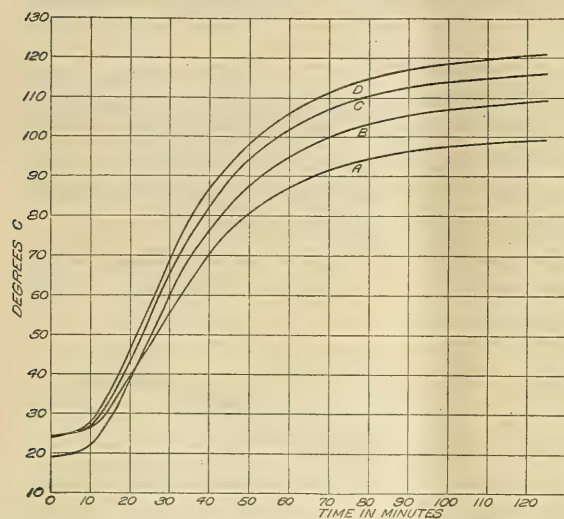


FIG. 37.—Time-temperature relations for pumpkin processed in No. 2 tin cans at 100°, 109°, 116°, and 121° C. These curves were plotted from temperature readings made at intervals of 5 minutes. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C.

free liquid to make possible any great amount of convection. The time-temperature curves for pumpkin are very similar to those for

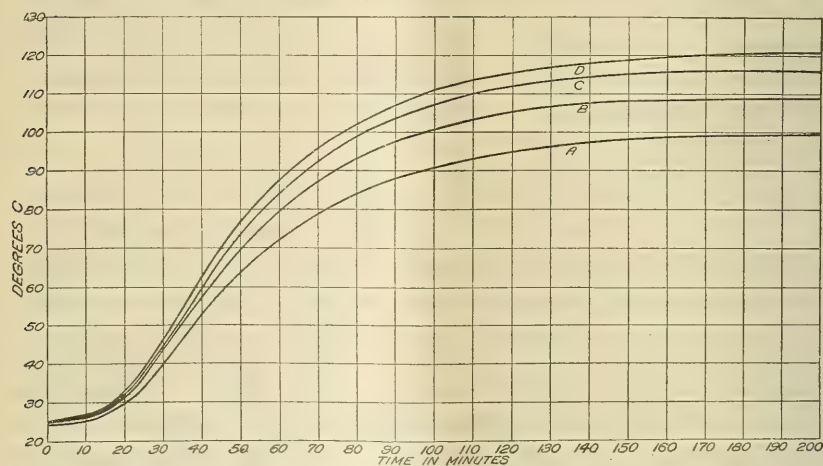


FIG. 38.—Time-temperature relations for pumpkin processed in No. 3 tin cans at 100°, 109°, 116°, and 121° C. These curves were plotted from temperature readings made at intervals of 5 minutes. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C.

sweet corn. Cooling tests in water were not made, and the curves for the cooling in air are omitted, as they add nothing of value.

were then cut into strips, the outer rind removed, and the pieces steamed for 30 minutes. After cooling, the pieces were ground in a food chopper in order to get a uniform pulp. This material, now in the form of pie stock, was packed in the cans. Figures 37 to 40 show the results of these tests.

As might be expected, the rate of rise in temperature is very slow, there being insufficient

The differences in the containers are the same as in the case of the sweet corn. The temperature rises fastest in the pint glass jar, the No. 2 tin can next, then the quart glass jar, and most slowly in the No. 3 tin can. The retarding influence of the glass ceases to be a factor here. This is because the conductivity of either the tin or the glass is greater than the conductivity of the material. Hence, the rate of temperature change at the center of the can follows the order of the diameters of the containers. This is true for sweet corn and pumpkin and also for sweet potatoes, as will be seen later. Sometimes pumpkin is concentrated before being canned. Evaporating the pulp to half its original volume would probably have only a small effect upon the rate of change of temperature. There is very little convection in the

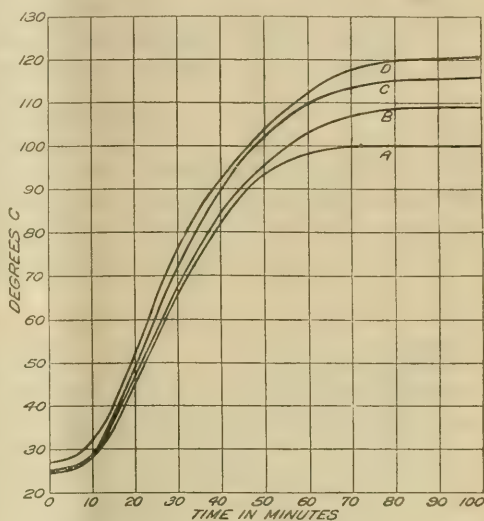


FIG. 39.—Time-temperature relations for pumpkin when processed in pint glass jars at 100°, 109°, 116°, and 121° C. These curves were plotted from temperature readings made at intervals of 5 minutes. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C.

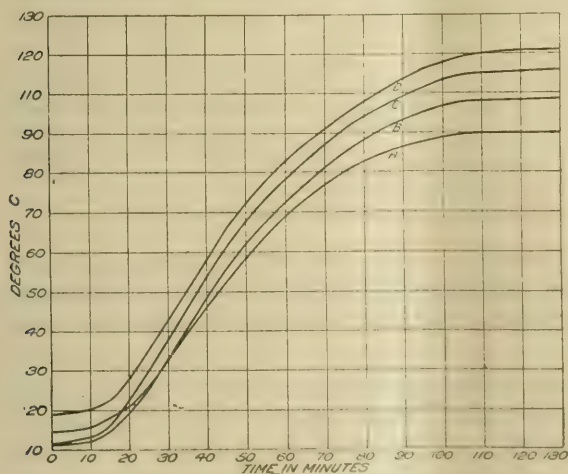


FIG. 40.—Time-temperature relations for pumpkin when processed in quart glass jars at 100°, 109°, 116°, and 121° C. These curves were plotted from temperature readings made at intervals of 5 minutes. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C.

material as thus prepared, so it is almost certain that evaporation to one-half would make it only slightly slower.

Some experiments were made to determine what effect cooking before filling into the can would have upon the temperature changes in the can. Cans were filled with raw material ground in the food chopper and with material which had been steamed 30

minutes and then ground in the food chopper and given identical processing temperatures. No appreciable differences were observed.

Tests were also made with summer squash prepared as described for the pumpkin. The time-temperature curves are practically the same. These curves have been omitted to save space.

SWEET POTATOES.

The variety of sweet potato used in these tests was the Nancy Hall. The potatoes were washed and steamed 30 minutes. After peeling they were allowed to cool and were then ground in a food chopper in order to get a uniform mash, commonly known as "pie stock."

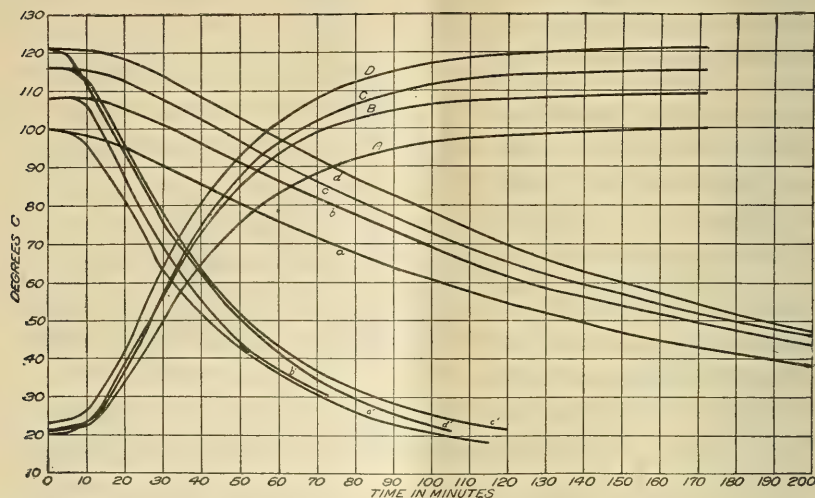


FIG. 41.—Time-temperature relations for sweet potatoes when processed in No. 2 tin cans at 100°, 109°, 116°, and 121° C. and also when cooled in air and in water. These curves were plotted from temperature readings made at intervals of 5 minutes. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C. Fall in temperature when cooled: *a*', From 100° in water at 15° C.; *b*', from 109° in water at 15° C.; *c*', from 116° in water at 15° C.; *d*', from 121° in water at 15° C.; *a*, from 100° in air at 20° to 24° C.; *b*, from 109° in air at 20° to 24° C.; *c*, from 116° in air at 25° to 25½° C.; *d*, from 121° in air at 25° to 25½° C.

Tests in glass were incomplete; hence time-temperature curves for these have been omitted. Figures 41 and 42 show the rise in temperature and also the cooling in air and in water for both No. 2 and No. 3 tin cans.

It will be seen that the temperature changes at the center of the can are very slow, in most cases slightly slower than in pumpkin or sweet corn. The necessity of a considerably longer processing period for the No. 3 tin can than for the No. 2 is again emphasized. Owing to the firmness of the pack and the absence of free liquid, convection currents play no part in the temperature changes here. Therefore, rotating the can in order to stir the material, as in an

agitating cooker. would have much less effect with sweet potatoes than the same treatment with sweet corn.

COMPARISON OF RAW AND COOKED MATERIAL.

Tests with sweet potatoes ground in a food chopper and packed into the can raw and with material cooked 30 minutes, ground, and packed into the can were made, the processing being conducted under identical conditions. There were no appreciable differences in the rate of change of temperature in the can. It is apparent that the gelatinization of the starch has little effect if the nature of the material at the outset is such that convection is prevented.

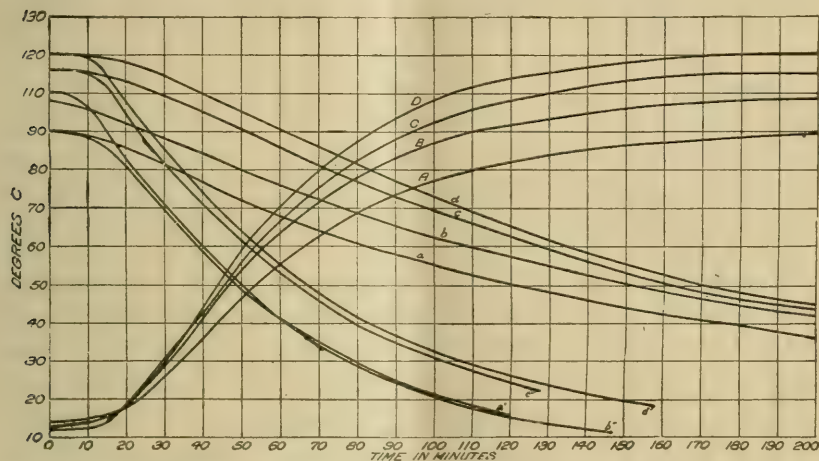


FIG. 42.—Time-temperature relations for sweet potatoes when processed in No. 3 tin cans at 100°, 109°, 116°, and 121° C. and also when cooled in air and in water. These curves were plotted from temperature readings made at intervals of 5 minutes. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C. Fall in temperature when cooled: a', From 100° in water at 15° C.; b', from 109° in water at 15° C.; c', from 116° in water at 19° C.; d', from 121° in water at 19° C.; a, from 100° in air at 18° to 22° C.; b, from 109° in air at 20° to 24° C.; c, from 116° in air at 25° to 25½° C.; d, from 121° in air at 25° to 25½° C.

PROCESSING FOR DIFFERENT LENGTHS OF TIME AT 116° C.

Figure 43 shows the result of a series of tests of No. 3 tin cans processed at 116° C. for 50, 60, 70, 80, 90, and 100 minutes and then put immediately into the air. The temperature of the air varied somewhat, so that the results are not exactly uniform. Two facts are brought out by this series of tests: (1) The temperature continues to rise for 20 to 30 minutes after the cans are put into the air; (2) at this processing temperature 90 to 100 minutes are required to carry the temperature at the center of the can to 100° C., or above. This is simply a "cut and try" method of finding the length of time necessary to sterilize any particular pack of canned material. If the cans had been left in the retort or put into water, the results would have

been entirely different. If the initial temperature of the material when put into the can had been higher, the maximum temperature attained would also have been higher.

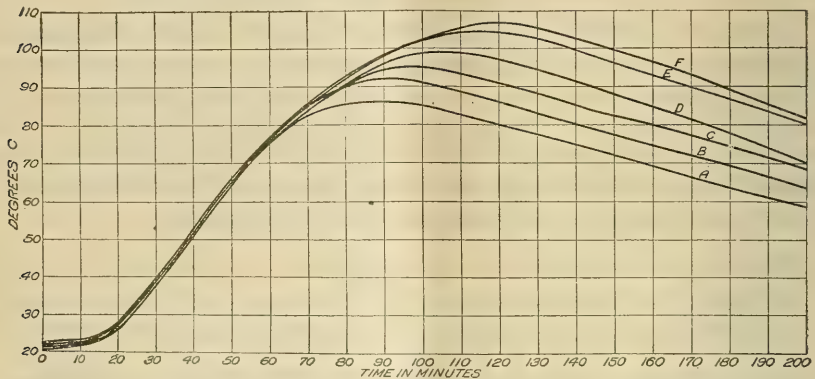


FIG. 43.—Time-temperature relations for sweet potatoes when processed in No. 3 tin cans at 116° C. for 50, 60, 70, 80, 90, and 100 minutes and then removed to the air at 20° to 25° C. These curves were plotted from readings made at intervals of 5 minutes. Temperature curve when processed and placed in air: A, For 50 minutes; B, for 60 minutes; C, for 70 minutes; D, for 80 minutes; E, for 90 minutes; F, for 100 minutes.

It is obvious that the initial temperature in the can should be uniform in all cans of the pack where the same processing is to be given, and the initial temperature should also be as high as pos-

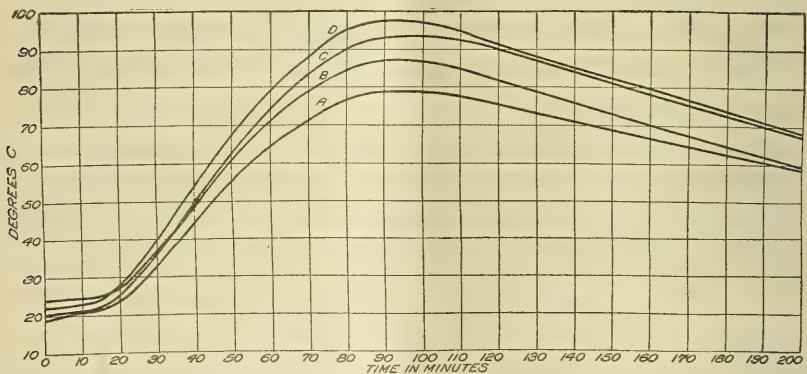


FIG. 44.—Time-temperature relations for sweet potatoes when processed in No. 3 tin cans for 1 hour at 100° , 109° , 116° , and 121° C. and then removed to the air at 20° to 25° C. These curves were plotted from readings made at intervals of 5 minutes. Temperature curves when processed for one hour: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C.

sible, in order that the processing period may be shortened. Starting at a temperature higher than that of the room is to be recommended.

PROCESSING FOR ONE HOUR AT DIFFERENT TEMPERATURES.

Figure 44 shows curves for No. 3 tin cans of sweet potatoes processed at 100° , 109° , 116° , and 121° C. for 1 hour in the retort, or

bath, and then removed immediately to the air. The temperature at the center of the can continues to rise for 20 to 30 minutes after it is put in the air. When the can is processed for 1 hour at 121° the temperature just approaches 100° C. If the can had been left in the retort instead of being put in the air, the temperature would have gone higher. This shows again the importance and necessity of knowing what temperatures are reached during the processing period. Such factors as these are often overlooked, when they are of very great importance. If the initial temperature had been different, it would have affected the maximum temperature attained. In processing sweet potatoes in No. 3 tin cans it is of very great importance to have the initial temperature as high as practicable.

TOMATOES.

The tomatoes used in these tests were of a special disease-resistant variety being studied at the Arlington Experimental Farm. They were fully ripened and of medium size. After scalding for two minutes in boiling water they were plunged into cold water to be peeled. After peeling they were packed into the cans as nearly whole as possible. No water or other liquid was added. Tests in both tin and glass containers were made, as usual. Cooling tests in air only were made. The temperature of

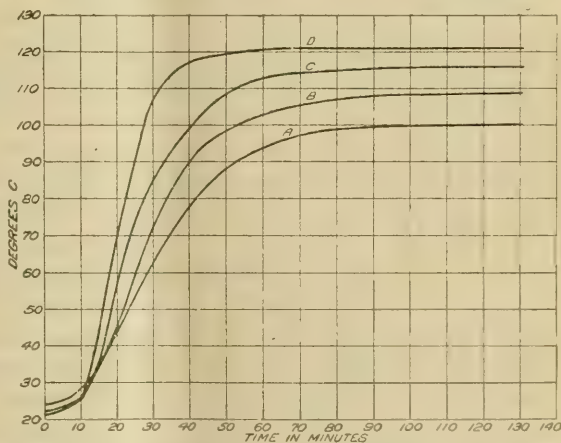


FIG. 45.—Time-temperature relations for tomatoes when processed in No. 2 tin cans at 100° , 109° , 116° , and 121° C. These curves were plotted from readings made at intervals of 5 minutes. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C.

the air varied considerably, so that the cooling in the various tests is not strictly comparable, and the curves were therefore omitted from the charts. The results showed, however, that the cooling would be somewhat slower than for string beans. Figures 45 to 48 show the results of these tests. Individual curves represent tests of a single can. Duplicate cans varied considerably, owing perhaps to inability to pack them exactly alike. The curves illustrate average results quite well, however.

The rate of change in temperature is faster than in pumpkin or sweet corn, but very much slower than in string beans. At 100° C.

it requires about 1 hour and 30 minutes to approach the temperature of the bath. At 109° C. it requires about 1 hour and 20 minutes,

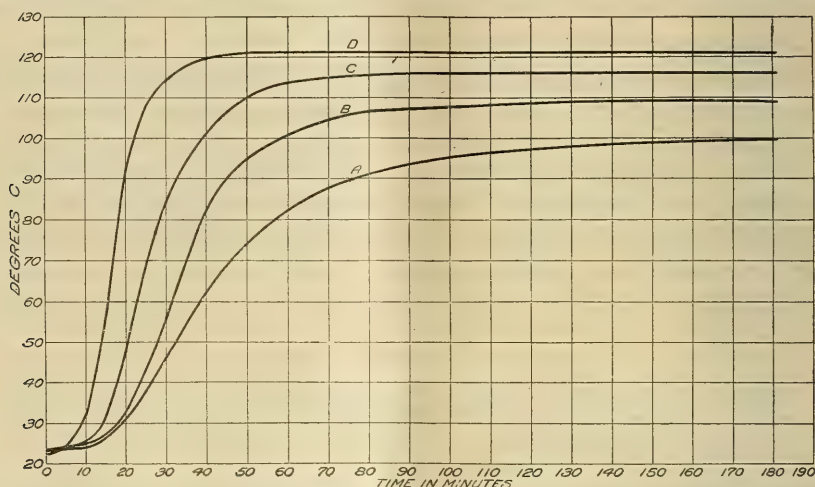


FIG. 46.—Time-temperature relations for tomatoes when processed in No. 3 tin cans at 100°, 109°, 116°, and 121° C. These curves were plotted from readings made at intervals of 5 minutes. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C.

at 116° about 1 hour and 10 minutes, and at 121° it requires 1 hour to reach the processing temperature in a No. 2 tin can. Similar

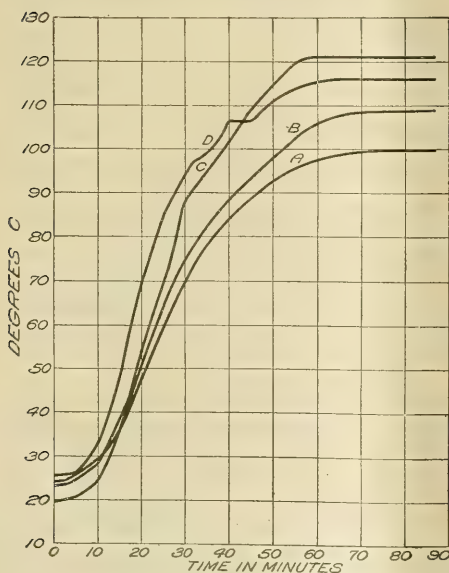


FIG. 47.—Time-temperature relations for tomatoes when processed in pint glass jars at 100°, 109°, 116°, and 121° C. These curves were plotted from readings made at intervals of 5 minutes. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C.

results are noticed in the No. 3 tin cans and in the pint and quart glass jars. A shorter time is required to reach the temperature of the retort at 121° than at any lower processing temperature. With many vegetables and fruits there is a slowing down in the rate of rise as the temperature goes higher, owing to the going into solution of starch, protein, or other material, which changes the viscosity of the material. This change in viscosity interferes with convection, and so the process is slowed down. A change of exactly the opposite character is taking place in the tomato. The tomato fruit is very succulent, and its tissues are easily broken down at high tempera-

tures. There is very little starch, pectin, or other readily soluble colloidal material in the tomato. It consists of organic acids and sugars, with insoluble cell tissues and a large amount of water. As a high temperature is reached the tissues begin to collapse, leaving a free liquid in which convection can take place. This explains the greater rate of temperature change at the higher processing temperature than at the lower.

Such high temperatures as 109° , 116° , and 121° C. are not necessary for the sterilization of the tomato, and the results are only of theoretical interest. Where it is of importance to keep the tissues of the material intact high temperatures should be avoided. It is of interest and importance to know just what temperatures are reached when the various cans are processed for 10, 15, 20, 25, 30, and 40 minutes each, but this work has not yet been completed.

The irregularities noted in the curves for tomatoes in the glass containers are due to the tendency of the material to rise to the top when it collapses under the high temperatures. The solid portion as it rises may for a time surround the thermometer, preventing convection, but later rises still higher, leaving the bulb of the thermometer in a liquid that is more or less free.

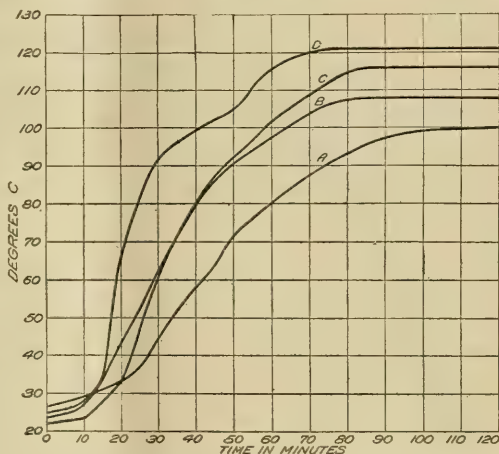


FIG. 48.—Time-temperature relations for tomatoes when processed in quart glass jars at 100° , 109° , 116° , and 121° C. These curves were plotted from readings made at intervals of 5 minutes. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C.

CABBAGE.

All cabbage plants used in these tests had firm heads, and the outer leaves were discarded. The heads were sliced somewhat coarser than for sauerkraut, with a rotary slicing machine. The sliced material was then blanched in flowing steam for 10 minutes, after which it was packed into the cans and enough water added to fill the interspaces. The results are shown in figures 49 and 50. The wide variation is due to inability to pack the cans exactly alike. In general when packed in this way the rate of change of temperature at the center of the can is very much slower than that of string beans, but considerably faster than that of sweet corn. Cabbage is the

only one of the leafy vegetables that has been included in these tests. The rate of change of temperature at the center of the can in the leafy vegetables depends upon the nature of the packing. If the cabbage in this case had been cut coarser and a little more water had been added, the rate of change would have been very much faster. On the other hand, if the material had been sliced finer and packed into the can a little closer, the rate would have been slower. Any alteration of the packing which would affect convection would affect the rate of change of temperature at the center of the can. In the leafy vegetables almost any results may be obtained between that of

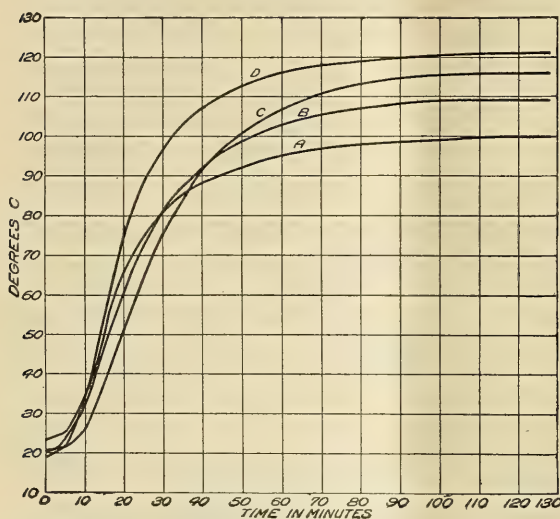


FIG. 49.—Time-temperature relations for cabbage when processed in No. 2 tin cans at 100°, 109°, 116°, and 121° C. These curves were plotted from readings made at intervals of 5 minutes. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C.

string beans and sweet corn. As usually packed, however, the changes are perhaps quite slow. This, again, shows how important it is to know how rapidly the temperature in the can approaches that of the retort.

FACTORS AFFECTING THE CHANGE OF TEMPERATURE AT THE CENTER OF THE CAN.

In considering the factors affecting the rate of change of temperature in the can the laws of heat transmission, especially the rapidity of

convection and the slowness of conduction and radiation, should be held in mind. From all the preceding experiments the following facts seem clear.

The first important factor is the size and nature of the container. If the rate at which the material in the can transmits heat is slower than the conductivity of the walls of the container, then the nature of the container ceases to be an important factor and the diameter of the container is the chief factor. If the rate at which the material carries heat to the center of the can is faster than the conductivity of the walls of the container, then the nature of the container is important and variation in its conductivity affects the temperature changes at the center of the can. Thus in string beans there is a difference in the rate of change of temperature in the tin and glass

due to the differences in the conductivity of the walls of the container, but in sweet corn the rate of change of temperature follows more nearly the order of the diameter of the container, the glass not being an important factor. The diameter of the container is of very much less importance in material where there is a free liquid in which convection carries the heat rapidly to the center of the can. Thus the difference in the rate of change of temperature in No. 2 and in No. 3 tin cans is so small in string beans that only slight differences in the processing periods are necessary.

Variations in the composition of the material are of importance when such variations affect convection. If the material is of such a nature that no convection occurs, its composition may vary widely without greatly affecting the temperature changes in the can. Thus

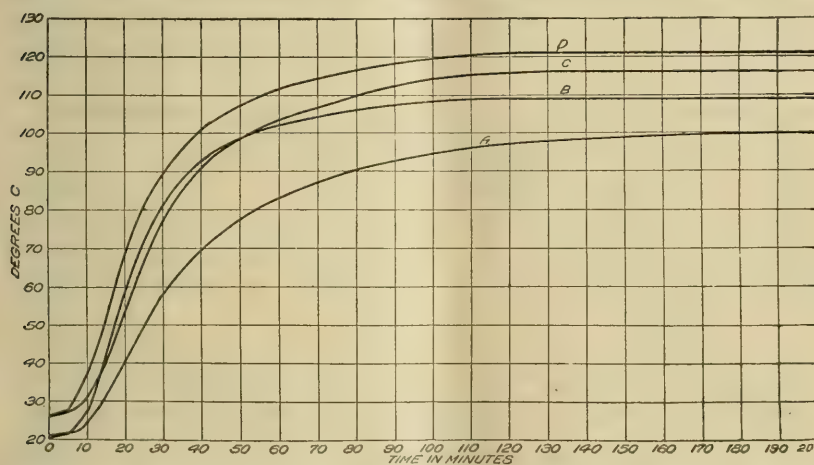


FIG. 50.—Time-temperature relations for cabbage when processed in No. 3 tin cans at 100°, 109°, 116°, and 121° C. These curves were plotted from readings made at intervals of 5 minutes. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C.

sweet potatoes and pumpkin, though of very different chemical composition, have similar time-temperature curves. The going into solution of starch may change the viscosity of the material and hence affect the temperature changes in the can, but changes in the physical nature of the starch have very little effect if the character of the pack at the outset is such that no convection can occur. In some cases there may be the cooking out of soluble proteins, pectins, or other viscous materials which would interfere with convection. Variations of materials in this respect must be considered in processing. Usually in processing where there is a breaking up of the material the rate of change of temperature becomes slower, but in the tomato the opposite is true, because the tomato contains little starch, pectin, or other mucilaginous material. The liquid becomes free, thus allowing convection.

The nature of the pack is one of the most important factors affecting the rate of change of temperature. In any material of any composition which is so packed that there is a free liquid filling in the interspaces between the pieces of material in the pack there is a very rapid change in temperature during processing. The temperature of the material approaches the temperature of the bath or retort very quickly. Any variation in the method of packing which interferes with convection alters the rate of change of temperature in the center of the can. The proportion of liquid to material is important, as has been shown under "Sweet corn." The fineness of division of the material is of importance because of the increased effect of surface tension in finely divided material. The fineness of division also affects the proportion of liquid to material.

The blanching or precooking affects the temperature changes if it in any way alters the nature or proportion of free liquid in the ma-

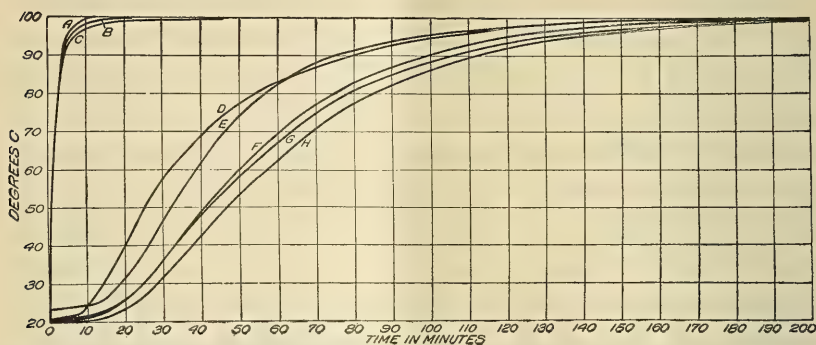


FIG. 51.—Time-temperature relations for different vegetables when processed in No. 3 tin cans at 100° C., as compared with distilled water. Curves A, B, and C were plotted from readings made at intervals of 1 minute, and curves D to H were plotted from readings made at intervals of 5 minutes. A, Distilled water; B, string beans; C, soy beans; D, cabbage; E, tomatoes; F, pumpkin; G, corn; H, sweet potatoes.

terial. Blanching the leafy vegetables would enable a closer pack to be made and would thus make the rate of change of temperature slower.

The heating and cooling medium is of importance. When the container is heated or cooled in the air the process is very slow. When it is heated in water or steam and when cooled in water, the process is very rapid, depending upon the other factors already pointed out.

Figure 51 shows curves for a large number of vegetables processed in No. 3 tin cans at 100° C. They fall pretty distinctly into two groups. The group having a free liquid with a consequent rapid rise in temperature contains by far the larger proportion of fruits and vegetables. This group includes string beans, Lima beans, soy beans, peas, and asparagus. In the second group, having

very little free liquid, the rate of change of temperature is very slow. In this group are sweet potatoes, sweet corn, pumpkins, and summer squash. Tomato and cabbage form a somewhat intermediate group.

INTERMITTENT PROCESSING.

Since sterilization by the intermittent process depends not only upon the maximum temperature attained, but also upon the length of the interval between processing periods and upon the temperature during this interval, it becomes of very great importance to understand thoroughly the time-temperature relations throughout the entire process. The first processing is supposed to destroy all vegetative forms of bacteria, and during the following interval any spores which may be present germinate and are killed during the second processing period. Any spores failing to germinate during the first interval are expected to germinate during the second interval and so are destroyed in the vegetative form during the third process. If the temperature during these intervals should be either too high or too low for the germination of any spores, then the whole process might fail. It is also known that spores of certain bacteria under optimum conditions germinate very quickly, multiply, and again form spores in a period of less than 24 hours. These facts make it highly important to understand the entire time-temperature relations.

In the experiments on the intermittent process a record of the processing temperatures, the temperature of the air to which the cans were removed after processing, and the temperature at the center of the can was kept during the entire period of 72 hours. The length of the processing period was exactly 1 hour. This treatment was given once on each of three successive days. String beans, corn, soy beans, and sweet potatoes were tested in this way.

STRING BEANS.

The variety of bean used was the Green Pod Stringless. The beans were washed and broken into pieces 1 to 1½ inches in length and blanched for five minutes in the boiling-water bath. They were cooled and packed into the cans and enough 2 per cent brine added to cover the material. They were then processed, as above stated. Figure 52 shows the results for No. 2 and No. 3 tin cans, and for pint and quart glass jars for the entire period.

During the first processing the temperature of the No. 2 and No. 3 tin cans approached that of the bath in about 10 minutes, the pint jar in about 25 minutes, and the quart jar in 30 minutes. The order of their heating up was No. 2 tin cans first, No. 3 tin cans next, then pint glass jars and quart glass jars last. The No. 2 and No. 3 tin

cans remained at about 100° C. for a period varying between 40 and 50 minutes each, and the pint and quart glass jars for a period between 25 and 30 minutes. At the end of one hour they were taken immediately from the bath and put in the air. The cooling was slow. The temperature fell to 60° C., as follows: No. 2 tin can, 1 hour and 25 minutes; No. 3 tin cans, 1 hour and 40 minutes; pint glass jars, 1

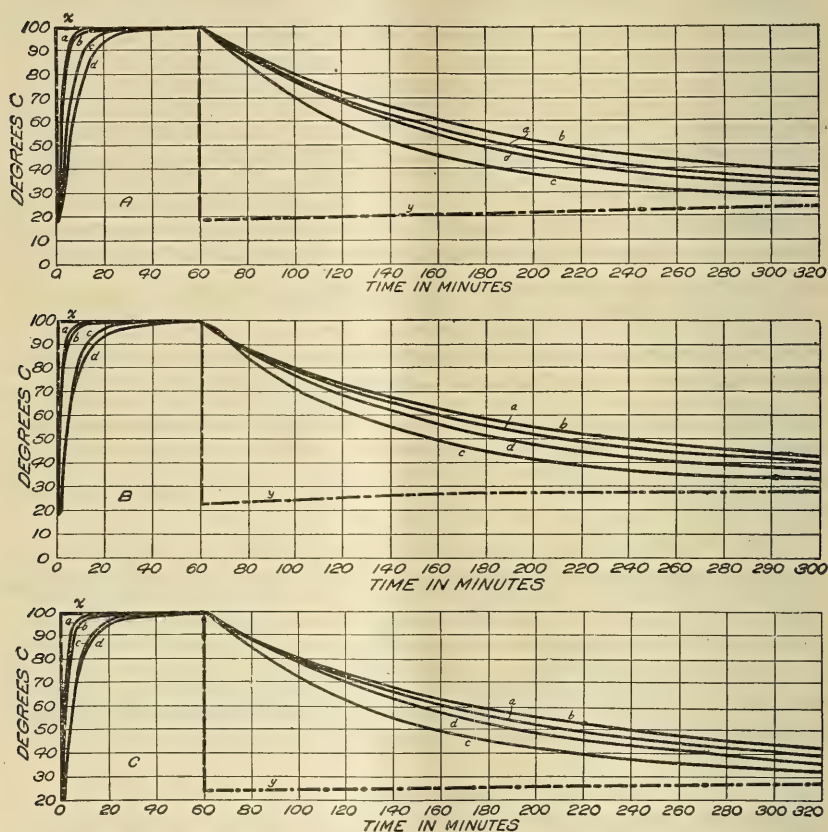


FIG. 52.—Time-temperature relations for string beans in various containers when processed for 1 hour on each of three successive days (the intermittent process) at 100° C. in the boiling-water bath: A, First day; B, second day; C, third day; a, No. 2 tin cans; b, No. 3 tin cans; c, pint glass jars; d, quart glass jars; x, temperature curve for water bath; y, temperature curve for room. The interval between the end of the curves in A and the beginning of the curves in B was 18 hours and 40 minutes. The same period of time elapsed between the end of the curves in B and the beginning of the curves in C.

hour; and the quart glass jars 1 hour and 20 minutes. The order of their cooling was pint jars fastest, quart jars next, then the No. 2 tin cans, and No. 3 tin cans slowest.

Since the optimum temperature for the germination of most bacterial spores is between 30° and 40° C., the length of time that the can remains at this temperature is important. It was found in this

case to be between 1 and $1\frac{1}{2}$ hours, which is probably sufficient to allow the germination of most spores. The temperature remained below 30° for the remainder of the 24 hours.

During the second processing the time-temperature relations were practically the same as during the first. The rate of change of temperature was very slightly slower, but this was insignificant.

The result of the third processing was essentially the same as the second. There was no change in the first heating, which affected materially the rate of change of temperature in the second and third processing.

SWEET CORN.

The variety of sweet corn used in these tests was Stowell's Evergreen. Ears which were in prime condition for canning were selected in the field. They were husked, the silks were removed with a coarse brush, and they were then washed in water. The corn was prepared "Maine style" and enough brine-sugar solution (2 per cent salt and 6 per cent sugar) was added to make the proportion 4.5 of corn to 1 of liquor. It was then processed for exactly one hour on each of three successive days. The time-temperature curves for No. 2 and No. 3 tin cans and for pint and quart glass jars are shown in figure 53.

The results shown here are very different from those for string beans. The temperature, instead of rising rapidly, went up very slowly. In no case did it reach 100° C. The temperature was rising when the cans were removed from the bath and continued to rise for a considerable time after being placed in the air. The pint glass jar went highest, the No. 2 tin can next, then the quart glass jar, with the No. 3 tin can lowest. The order in which they heated up was different from that of string beans. All the cans went above 80° C., which is sufficient to destroy most vegetative forms of bacteria. The cooling was quite slow. The temperature fell to 60° C. about as follows: No. 2 tin can, 2 hours and 5 minutes; No. 3 tin can, 2 hours and 20 minutes; pint glass jar, 1 hour and 25 minutes; and quart glass jar, 1 hour and 50 minutes. The temperature of the containers remained between 30° and 40° C., as follows: No. 2 and No. 3 tin cans, 3 hours; the pint glass jars, 2 hours and 20 minutes; and the quart glass jars, 2 hours and 45 minutes. For the remainder of the time the temperature remained below 20° C., reaching 19° over night.

The initial temperature in the second processing was lower than in the first, and consequently the maximum temperature reached was lower. The curves took nearly the same form the second day as the first, showing that there had been but little alteration in the rate of change of temperature at the center of the can. The results were quite similar to those of the first processing. The results for the third processing were essentially the same as for the second.

SOY BEANS.

The variety of soy beans used in these tests was the Easy Cook. The beans were closely approaching maturity, as the pods were beginning to turn yellow. After gathering from the field they were placed upon trays and steamed five minutes at 100° C. This softened the pods so that they could be easily shelled by hand. The shelled

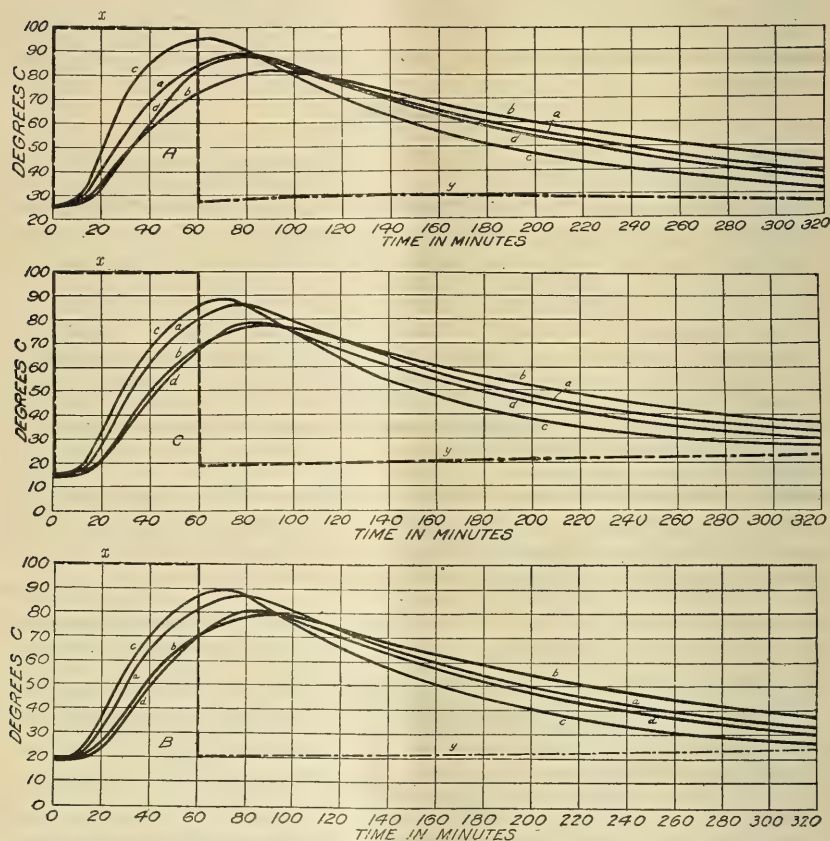


FIG. 53.—Time-temperature relations for sweet corn (Maine style) in various containers when processed for 1 hour on each of three successive days (the intermittent process) at 100° C. in the boiling-water bath: *A*, First day; *B*, second day; *C*, third day; *a*, No. 2 tin cans; *b*, No. 3 tin cans; *c*, pint glass jars; *d*, quart glass jars; *x*, temperature curve for water bath; *y*, temperature curve for room. The interval between the end of the curves in *A* and the beginning of the curves in *B* was 18 hours and 40 minutes. The same period of time elapsed between the end of the curves in *B* and the beginning of the curves in *C*.

beans were then placed in the cans and enough 3 per cent brine was added to cover the beans. They were then processed for exactly 1 hour on each of three successive days. Figure 54 shows the time-temperature record for the entire period of 72 hours for No. 2 and No. 3 tin-cans and for pint and quart glass jars.

During the first processing there was a very rapid rise in temperature. The No. 2 tin can was fastest, with the No. 3 tin can next, then the pint glass jar with the quart glass jar slowest. The temperature approached 100° C. promptly, thus subjecting the material to that degree of heat for a considerable length of time. The cooling was rather slow, the pint jar being fastest, the quart jar next, then the

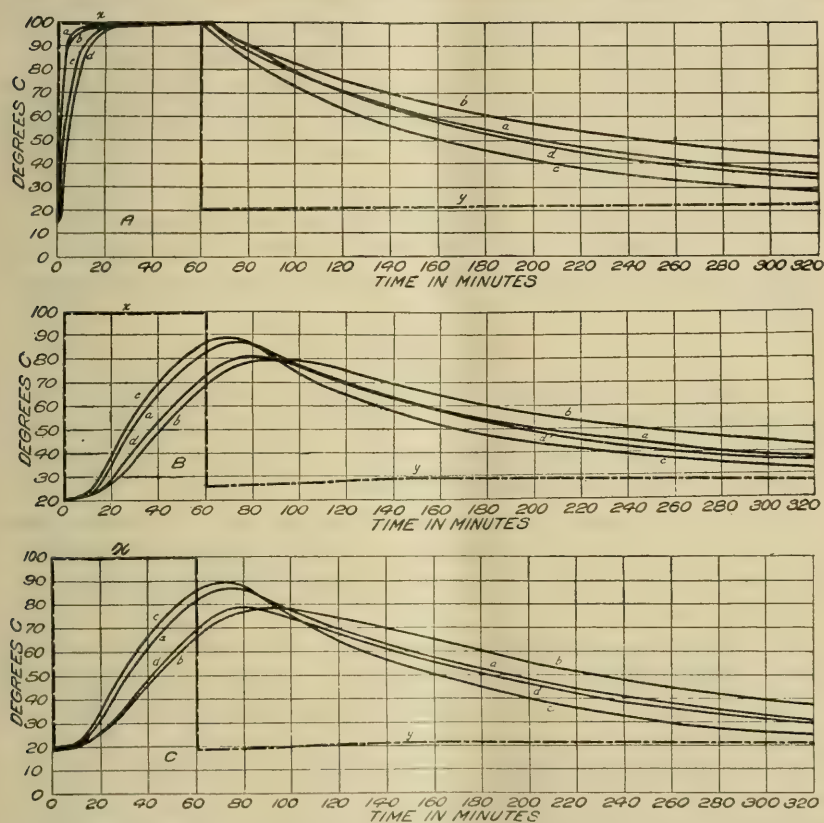


FIG. 54.—Time-temperature relations for soy beans (Easy Cook) in various containers when processed for 1 hour on each of three successive days (the intermittent process) at 100° C. in the boiling-water bath: A, First day; B, second day; C, third day; a, No. 2 tin cans; b, No. 3 tin cans; c, pint glass jars; d, quart glass jars; x, temperature curve for water bath; y, temperature curve for room. The interval between the end of the curves in A and the beginning of the curves in B was 18 hours and 40 minutes. The same period of time elapsed between the end of the curves in B and the beginning of the curves in C.

No. 2 tin can, with the No. 3 tin can slowest. The temperature fell to 60° C. in about 1 hour and 15 minutes in the pint glass jar, in $1\frac{1}{2}$ hours in the quart glass jar, in 1 hour and 35 minutes in the No. 2 tin can, and in 2 hours in the No. 3 tin can. The temperature remained between 30° and 40° C. in the different containers as follows: Pint glass jar, $1\frac{1}{2}$ hours; quart glass jar, 1 hour and 45 minutes;

No. 2 tin can, 2 hours and 25 minutes; and No. 3 tin can, 5 hours. The temperature fell to about 20° C. over night.

The time-temperature relations were entirely different in the processing on the second day. The temperature change was very much slower, as during the first processing the soluble proteins cooked out into the liquid to such an extent as to form a colloidal jelly. The change in consistency of the liquor was such that all convection was prevented in the second processing, and the heat passed in only by conduction. The temperature curves for the second heating were almost exactly the same as those of sweet corn. As in sweet corn, the temperature did not reach 100° C. at any time. The third processing was entirely similar to the second.

The very slow rate of change of temperature in the second and third periods of processing increased very greatly the possibility of an incomplete sterilization. Therefore, a period longer than 1 hour for the second and third processing would decrease the possibility of spoilage.

SWEET POTATOES.

The variety of sweet potato used in these tests was the Nancy Hall. The potatoes were washed, steamed for 30 minutes, peeled, and allowed to cool. They were then ground in the food chopper in order to get a uniform mash commonly known as "pie stock." This was placed in the cans and processed for 1 hour on each of three successive days, as in the preceding tests. Figure 55 shows the time-temperature records for No. 2 and No. 3 tin cans and for pint and quart glass jars.

The rate of rise in temperature was very slow, in no case reaching 100° C. during the processing. The maximum temperature attained, between 80° and 90° C. in the different containers, was reached at a considerable time after removal from the processing bath. The highest temperature was reached in the pint glass jar, the No. 2 tin can being next, then the quart glass jar, and the No. 3 tin can the lowest. The cooling was as might be expected from material of this sort. The temperature remained above 80° C. long enough to destroy most vegetative forms of bacteria. The results of the second and third period of processing were entirely similar to the first.

FACTORS INFLUENCING THE RATE OF CHANGE OF TEMPERATURE.

All those factors discussed under the heading "Single-period processing" apply to the first period of the intermittent process.

In addition to these factors the first period of the processing has an effect upon the material as treated during the second and third periods. As already observed in soy beans, there is often a change in the material during the first processing period which greatly affects

the temperature changes in the second period. To show clearly the differences that sometimes occur the following experiment was carried out.

Apples, pumpkin, and sweet potatoes were cut into half-inch cubes. These were placed raw in No. 3 tin cans and enough water added to cover the material. Also, soy beans were packed in cans in the same way and enough water was added to cover the material. These were

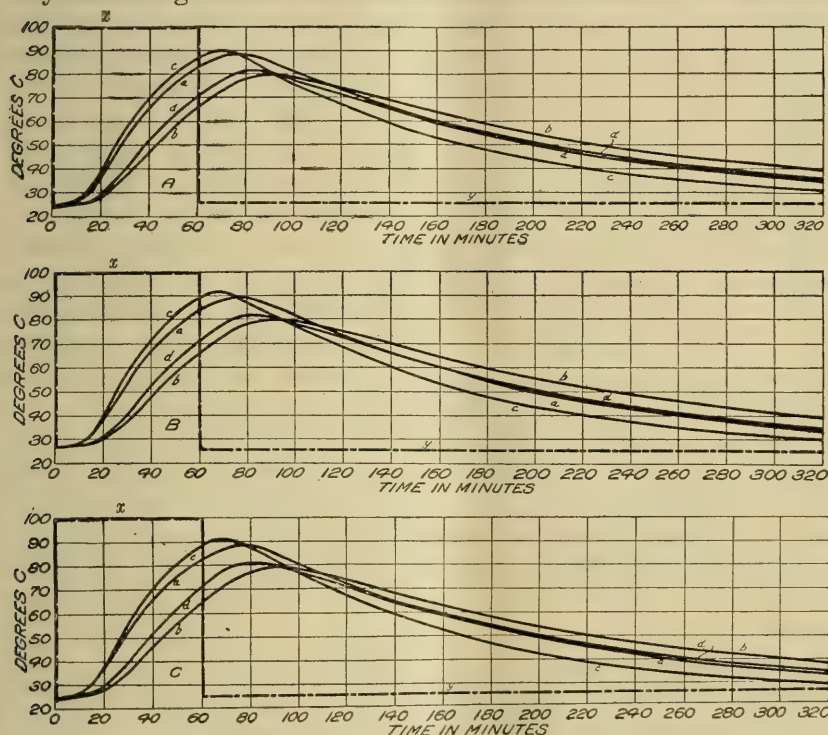


FIG. 55.—Time-temperature relations for sweet potatoes in various containers when processed for 1 hour on each of three successive days (the intermittent process) at 100°C . in the boiling-water bath: A, First day; B, second day; C, third day; a, No. 2 tin cans; b, No. 3 tin cans; c, pint glass jars; d, quart glass jars; x, temperature curve for water bath; y, temperature curve for room. The interval between the end of the curves in A and the beginning of the curves in B was 18 hours and 40 minutes. The same period of time elapsed between the end of the curves in B and the beginning of the curves in C.

then processed in the water bath for 1 hour. On the following day they were processed a second time. Figures 56 and 57 show the results.

In the pumpkin very little difference in the time-temperature curve for the first and second processing is noted. During the first period the rise of temperature was rapid, and it was almost equally so in the second processing.

In the apples there was a very marked slowing down of the rate of change of temperature, owing to the cooking out of pectin which changed the viscosity of the liquid filling the interspaces. The in-

creased viscosity interfered with convection and thus cut down the rate at which heat penetrated to the center of the can.

In the sweet potatoes the differences noted are extremely great. During the first processing the free liquid surrounding the pieces of

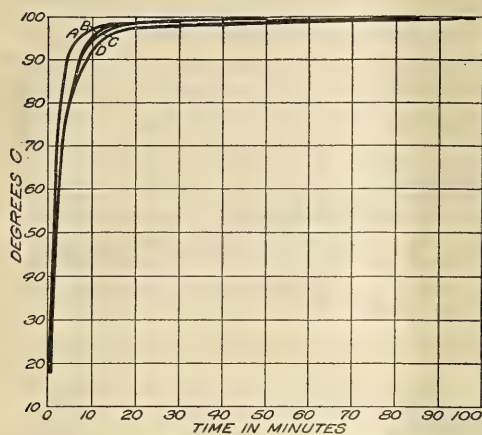


FIG. 56.—Diagram showing the effect of the first processing of different vegetables upon the rate of change of temperature. These curves were plotted from readings made at intervals of 1 minute. A, Soy beans; B, pumpkin; C, apple; D, sweet potatoes.

material was converted into a starch jelly by the cooking out of the starch during the processing, so that during the second processing the heat passed to the center only by conduction.

In the case of the soy beans the same change of rate of rise in temperature is noted, though the material that changed the viscosity of the liquid filling the interspaces between the beans was protein, and not pectin or starch.

As heretofore noted, any material which alters the viscosity of the liquid fill-

ing the interspaces between the pieces of material will affect the rate of change of temperature in the can. It may depend upon the going into solution of pectins, starch, proteins, or any other mucilaginous material.

If sweet potatoes or pumpkins are ground in a food chopper and packed closely in the cans, there is no difference in the first and second heating. If the material at the outset is of such a nature that all convection is stopped, then the going into solution of starch or protein has little effect upon the temperature changes in the can.

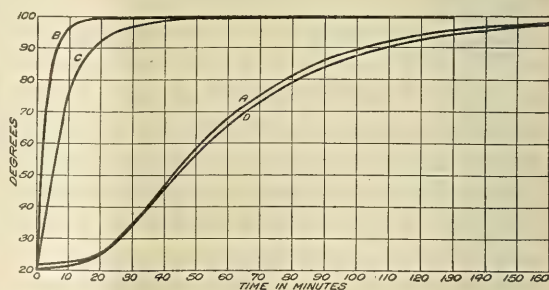


FIG. 57.—Diagram showing the effect of the second processing of different vegetables upon the rate of change of temperature. Curves A and D were plotted from readings made at intervals of 5 minutes; curves B and C were plotted from readings made at intervals of 1 minute. A, Soy beans; B, pumpkin; C, apple; D, sweet potatoes.

Any change in the material which affects the freedom of convection affects the rate of temperature change. It may be the solution

of some viscous substance, as in the soy beans; or it may be simply a compacting of the material, as happens sometimes in the case of the leafy vegetables; or it may be the evaporation of the liquid, as might happen sometimes in glass where an absolutely tight closure can not be made.

SUMMARY.

(1) The mercury thermometer is sufficiently accurate for practical work in the determination of temperature changes in the canning of food materials if it is properly calibrated and standardized.

(2) A satisfactory apparatus has been devised for measuring the temperature changes at the center of the can during the processing period and the subsequent cooling, which permits the use of the mercury thermometer both in the water bath and in the steam retort.

(3) In a can packed with material having an interspace filled with a free liquid, as in string beans, the rate of change of temperature at the center of the can is very rapid, and in materials of a heavy or pasty nature, as in sweet corn, the rate is very slow unless mechanical agitation is employed.

(4) In canned materials the character of the pack and the composition of the material very largely determine the rate of change of temperature in the can. The fineness of division and compactness of the material and the amount and viscosity of the free liquid are the factors which influence the rate of change of temperature. Variations in the composition of the material, however, have very little effect if the consistency of the material is such that no convection can occur.

(5) Sodium chlorid has very little direct effect upon the rate of change of temperature in the can. Dilute sugar solutions have only a small effect, but the concentrated solutions have a considerable effect in retarding the rate of change. Solutions of starch have a very marked retarding effect upon the rate of change of temperature at the center of the can. The retarding effect increases very rapidly from 2 to 5 per cent. In 5 per cent starch the consistency becomes such that all convection is stopped and the rate of change is very slow. Increasing the percentage of starch further has very little effect upon the temperature changes. Also, any other material of a viscous nature, such as protein or pectin, retards the rate of change of temperature.

(6) The glass container has a marked retarding effect upon the rate of rise in temperature in those materials in which there is a free liquid, as in string beans, but is of little importance in materials of a heavy consistency, such as sweet corn. On the other hand, glass cools faster in the air than tin, owing to its greater power of radiation.

(7) Differences in the diameter of the container are of much less importance in those materials in which there is a free liquid than in materials of heavy consistency. Thus there need be little difference in the processing period of No. 2 and No. 3 tin cans of string beans, but there must be considerable difference in the processing period of No. 2 and No. 3 tin cans of sweet corn.

(8) The temperature of the bath or retort is reached in the container in approximately the same time, whether the processing temperature is 100°, 109°, 116°, or 121° C. Tomatoes are a striking exception to this rule, because the higher temperatures break down the tissues of the fruit.

(9) The difference in the rate of cooling in the air and water is very marked. In materials having a free liquid the cooling is exceedingly rapid, as in string beans, but is considerably slower in materials having a heavy consistency, as in sweet potatoes. Cooling in air is always very much slower than cooling in water.

(10) Since a steam-tight closure in glass containers can not be made, any temperature above 100° falls to 100° as rapidly as the temperature of the retort, so that the temperature is always 100° or below when removed from the retort.

(11) In the intermittent process, the first processing period may or may not affect the rate of temperature change in the second processing period, depending upon the composition and nature of the material. Any change during the first processing period which interferes with convection retards the rate of change of temperature during the second processing period. This change may be the simple compacting of the material, the going into solution of starch, protein, pectin, or any other mucilaginous material. If the material at the outset is such that no convection occurs, then the gelatinization of starch or other such change has very little effect upon the rate of change of temperature in the can.

(12) The fruits and vegetables as processed in these tests fall roughly into two groups, with reference to time-temperature relations. The first group consists of those fruits and vegetables packed so that there is a free liquid filling the interspaces between the pieces of material. The rate of change of temperature in this group is very rapid. The second group consists of those materials that are packed in such a way that little or no convection can occur. The rate of change of temperature in this group is very slow.

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WM. A. TAYLOR, Chief



Washington, D. C.

PROFESSIONAL PAPER

February 6, 1922

INVESTIGATIONS OF THE WHITE-PINE BLISTER RUST.

By PERLEY SPAULDING, *Pathologist, Investigations in Forest Pathology.*

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SCOPE OF THE INVESTIGATIONS.

In a previous publication (131)¹ the writer collected data on the more practical aspects of the white-pine blister rust, as presented in European literature.

Experience has shown that the white-pine blister rust has come to North America to stay and that most careful and searching investigations must be maintained to enable us to cope with it at all successfully. Investigations in Europe have been carried on in a desultory way for 35 years. In North America they were begun less than 15 years ago. Really intensive work has been in progress for only about 5 years. Considerable new experimental work has been done in Europe since the appearance of this earlier publication. At various times since 1911 some of the more salient results of the investigation of *Cronartium ribicola* Fischer and the disease caused by it have been published (132 to 148, 180). During the years 1915 to 1919, inclusive, publication has fallen far behind the investigations.

¹ The serial numbers in parentheses refer to "Literature cited" at the end of this bulletin.

No attempt has ever been made to collate and summarize the results of all the experimental work. The mass of information is so large and so scattered that it is nearly impossible for a single individual, even now, to learn what has been done. This condition is certain to become more and more acute as the extensive and intensive researches now under way progress. Various States are taking up work on this disease, and the multiplication of workers can only result in confusion and unnecessary duplication of work unless the ascertained data are arranged and made available for all. This bulletin aims to present the available information so that the gaps in our knowledge may be readily perceived and new investigations planned to the best advantage.

The work of the Office of Investigations in Forest Pathology has been conducted under the direction and advice of the writer by the following persons: In 1915, G. F. Gravatt and Dr. G. R. Lyman; in 1916, Dr. R. H. Colley, G. F. Gravatt, and Miss M. W. Taylor; in 1917, Dr. R. H. Colley, G. B. Posey, G. F. Gravatt, Rush P. Marshall, and Miss M. W. Taylor; in 1918, Drs. R. H. Colley, H. H. York, L. H. Pennington, L. O. Overholts, A. S. Rhoads, T. C. Merrill, W. H. Snell, D. M. Benedict, and Miss M. W. Taylor; in 1919, Drs. R. H. Colley, H. H. York, and L. H. Pennington, D. M. Benedict, J. E. Lodewick, W. H. Snell, P. R. Gast, Miss A. E. Rathbun, and Miss M. W. Taylor. Dr. G. G. Hedgcock made a comparative study of *Cronartium occidentale* and *C. ribicola* on Ribes on Block Island, R. I., in 1919.

The work of Dr. L. H. Pennington, D. M. Benedict, and J. E. Lodewick, in 1919, was maintained in formal cooperation with the New York State College of Forestry at Syracuse University.

The endeavor has been to show plainly in this bulletin who did each piece of work without entering into details to an objectionable extent.

The writer thanks the following people for unpublished data which have been placed at his disposal: Mr. W. A. McCubbin, formerly of Canada; Dr. Ed. Fischer, of Switzerland; Dr. A. B. Borthwick, of Scotland; Mr. A. D. Cotton, of Kew Gardens, England; Prof. L. Mangin, Museum of Natural History, Paris; Prof. F. Kølpin Ravn and Mr. J. Lind, of Denmark; Dr. L. O. Kunkel and Mr. W. Stuart Moir, of this country.

The writer and his collaborators are indebted for material for experimental use to the Arnold Arboretum of Harvard University; the Dominion of Canada Central Experimental Farms; the Park Board of Rochester, N. Y.; the Conservation Commission of the State of New York; the Office of Horticultural and Pomological Investigations and the Forest Service, of the United States Department of Agriculture. The Office of Blister-Rust Control has contributed

data, especially toward that appearing in the chapter on control, Table V, and the list of *Ribes* species infected in the different States. Much difficulty has been encountered in getting satisfactory translations of articles published in the Japanese, Russian, Dutch, Swedish, Norwegian, and Danish languages. Dr. E. P. Meinecke has very kindly translated most of the Scandinavian and Danish articles. Mr. Rush P. Marshall and Miss M. W. Taylor, have aided in checking and collating the extensive data here presented.

In this bulletin the behavior of *Cronartium ribicola* is given with considerable detail. So far as is now known, it agrees essentially with the Uredinales in general in its life history and physiology. This is the first species of *Cronartium* to be very intensively investigated, and as a representative of this important group of forest-tree fungi, a detailed knowledge of its life history must form the basis for the institution of new methods of management of white-pine forests.

ORIGIN AND DISTRIBUTION OF CRONARTIUM RIBICOLA.

Some writers (76, 90) have believed that *Cronartium ribicola* went to Europe from America on *Ribes aureum*, that host being associated with it (but not exclusively) in the earlier discoveries of the disease in Europe. Magnus, who was of this opinion at first (90), seems to have completely rejected this theory and now believes that the disease came from western Siberia and the Swiss Alps, where it is supposed (26, 39, 40, 93, 130, 174) to have been endemic on *Pinus cembra*. In 1842 Klotzsch issued in the *exsiccatae* entitled "*Herbarium vivum mycologicum*, No. 490," a specimen labeled "*Uredo ribicola*" collected by Lasch at Driessen. Specimens have not been seen by the writer, and there is some uncertainty whether or not this is actually the uredinial stage of *Cronartium ribicola*. Sydow (155) gives it as a synonym of *C. ribicola*, but he is the only author known to the writer who does so.

Cronartium ribicola was first certainly found by Dietrich (27) in the Baltic provinces of Russia in 1854. He found it upon *Ribes nigrum*, *R. "rubrum,"* and *R. "palmatum,"* and also upon *Pinus strobus*, although at that time it was not known that the two forms were stages of a single fungus. So far as can be determined from scientific literature, it was not again noted until 1861 in Finland (81), 1865 in East Prussia (76), and 1869, when Eriksson (31) found it in Sweden on *Ribes nigrum*, and Hisinger (54) noted the first outbreak on pines in Finland. It had attacked *Pinus strobus* trees 30 years old and killed them. In 1883 Røstrup (115) reported an outbreak in Denmark on *Pinus strobus* trees 20 to 30 years old. It was evidently then generally spread over that country. Still later, Klebahn (62, 63) and Tubeuf (169) record it as generally distributed over

Germany, and soon it had spread over the northern countries of Europe (91, 92, 93). It seems to the writer that this was an instance of the introduction of a foreign disease into Europe and its destructive spread over most of that continent (39, 40). The fact that *Pinus strobus* had been grown extensively in Europe since its introduction there in 1705 (5), but was not known to have this disease until about 1855, in the light of our experience with this and other introduced plant diseases in North America, shows that this was a new disease which had reached Europe probably years before its discovery.



FIG. 1.—Outline map of the Old World, showing the approximate distribution of *Pinus cembra* (oblique hatching) and of its variety *pumila* (vertical hatching) together with the known distribution of *Cronartium ribicola* (black dots). Tree distribution furnished by the Forest Service, United States Department of Agriculture.

It is not certain that *Cronartium ribicola* is a native of the Swiss Alps (174). Schellenberg (123), in 1903, found *Cronartium ribicola* on a single 15-year branch of a tree of *Pinus cembra* about 200 years old in the Engadine Valley, Switzerland. He believed that the fungus was native there on this host. Yet this is the first known finding of the fungus on pine in that region. *Ribes* diseased with it were found there in 1895 (39, 123), showing it to be established in that locality then. It seems to the writer that the circumstances point plainly to the fungus having come into Switzerland some time previously, and that it is not endemic there; else it would have been

found much earlier, and more of it would have been found since then. Fischer (40) found the disease in 1915 spreading into western and northern Switzerland from without.

It is generally supposed that *Pinus cembra* (26, 70, 93, 97, 98, 123) is the original pine host of this fungus. Figure 1 shows the distribution of *P. cembra* and its variety *pumila* in Europe and Asia. *Cronartium ribicola* is reported from Asia as follows: In 1879, from

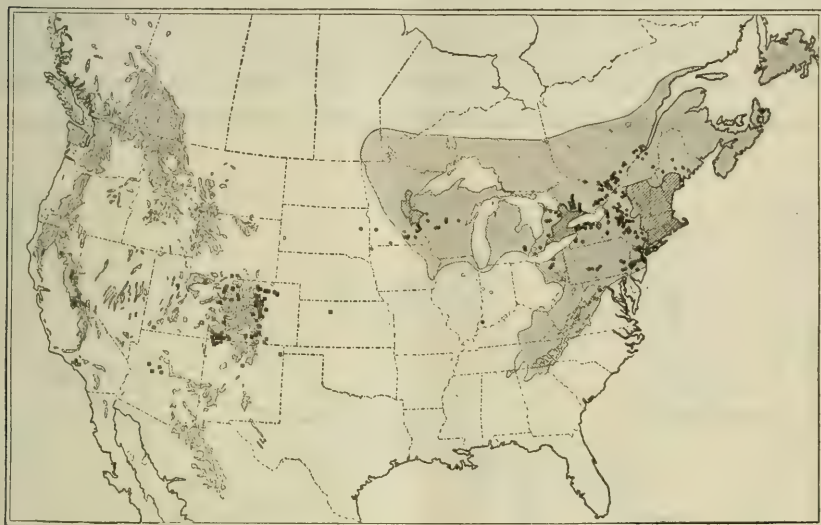


FIG. 2.—Outline map of the United States, showing the known distribution of *Cronartium ribicola* and *C. occidentale* in North America to January 1, 1920. Localities for *Cronartium occidentale* are shown by black squares in the Pacific coast and Rocky Mountain regions, the easternmost point being in western Kansas. This is where it was found in 1892, but it has not been seen there since. Localities for *C. ribicola* are indicated by double cross hatching and black dots, nearly all being north of the Potomac and Ohio Rivers and east of the Mississippi River. Four points in southwestern Minnesota, eastern South Dakota, and northern Iowa were found to be due to diseased nursery stock which was shipped in. It is believed that the disease now has been eradicated in these outer western localities. The natural distribution of the eastern white pine is shown in the large cross-hatched area mostly east of the Mississippi River. The cross-hatched areas shown on the western half of the map indicate the known distribution of the western white pines. The piñon pines range as far north as southern Idaho but at altitudes different from those of the white pines. *Cronartium ribicola* is limited to the eastern white-pine area and was not known in North America until 1906. In most places where now found it has been traced to diseased imported white-pine stock. *Cronartium occidentale* is limited to that part of the western white-pine area in which piñon pines are native, where it appears also to be native. The two fungi are separated by a strip of prairie country about 500 miles wide. Distribution of the pines furnished by the Forest Service, United States Department of Agriculture. Distribution of *Cronartium occidentale* furnished by Messrs. Bethel and Posey, of the Offices of Investigations in Forest Pathology and of Blister-Rust Control, respectively.

Bolschaja Inja River (131, 161); also from Tomsk and Minusinsk, Siberia (131). Quite recently it has been reported from Sakhalin Island and from Sapporo, Japan (156). Tulasne (175) in 1854 reported a *Cronartium* on *Ribes*, probably in India. Clinton has announced (13) the finding of *Cronartium ribicola* on dried herbarium specimens of *Ribes* collected by Wilson in the western part of the Province of Hupeh, China, in 1900.

To sum up briefly: *Pinus cembra*, the probable original pine host, ranges across northern Asia; and the fungus is reported from western, eastern, and central Asia, in some places where it may easily be endemic.

In North America, *Cronartium ribicola* was first found in 1906 at Geneva, N. Y. (3, 150). Later findings have indicated that it was here in the Northeastern States as early as 1898 (108, 136, p. 6). It might have been in North America a few years, but not many, before that date. This is supported by Clinton (13), who unsuccessfully examined specimens of *Ribes* which are in some of the larger herbaria of the eastern part of this country. The writer has supplemented



FIG. 3.—Outline map of the northeastern part of the United States, showing (by black dots) the known distribution of white-pine blister rust in North America to and including 1909.

Clinton's work by examining the *Ribes* specimens in several additional herbaria. These include the Pringle herbarium at the University of Vermont and the local collections of the University of Vermont; of Dartmouth College; of President Ezra Brainerd, of Middlebury College; of Mr. C. A. Weatherby, of East Hartford, Conn.; and of Mr. C. H. Bissell, of Southington, Conn. The most notable herbarium examined was that of the Boston Society of Natural History, which contains many New England collections made in the early years of the nineteenth century. Moreover, such keen fungus collectors as Farlow, Seymour, G. P. Clinton, Peck, Ellis, George Clinton, Stewart, and many others, never collected *Cronartium ribicola* until 1906, showing that it is a recent immigrant. Since 1909, when it was first found in North America on white pines, *Cronartium ribicola* has spread until it is firmly estab-

lished in New England, New York, Wisconsin, Minnesota, and Canada.

It has been known since 1892 that there was a fungus on *Ribes* in the West much resembling *Cronartium ribicola*, but until 1917 its alternate stage on pines was unknown. In that year the Office of Investigations in Forest Pathology began work upon this western fungus, which was soon found to have an alternate stage on *Pinus edulis* and *P. monophylla* in Colorado and Arizona (50, 114) and was named *Cronartium occidentale*. Its distribution and that of *C. ribicola* as known to January 1, 1920, is shown on the map (fig. 2). See figures 3 to 12 for the progress of *C. ribicola* by years from 1909 to



FIG. 4.—Outline map of the northeastern part of the United States, showing (by black dots) the known (cumulative) distribution of white-pine blister rust in North America to and including 1910.

1918, inclusive. *Cronartium occidentale* is found in localities where it could hardly be an introduction, as the Ute Indian Reservation in southwestern Colorado, where it was found by Bethel in 1897; also in the Mesa Verde region, where no cultivated *Ribes* or pines have ever been introduced. *Ribes aureum* is native in the Rocky Mountain region and is a favorite host for *Cronartium occidentale* as well as *C. ribicola*.

Since *Ribes aureum* was intimately associated with *Cronartium ribicola* in its earlier known occurrences in Europe, an inquiry has been made into the possibility of the fungus being American in origin and its being introduced into Europe on *R. aureum* when that plant was first sent there. The facts thus far determined are² that *R. aureum*

² Spaulding, Perley. *Ribes aureum* not an original host of *Cronartium ribicola*. In manuscript. To be published in *Phytopathology*.

is definitely stated to have been introduced into England (the probable first point of introduction in Europe) in 1812 by Thomas Nuttall. Evidently Nuttall collected the seeds of this plant while on a botanical

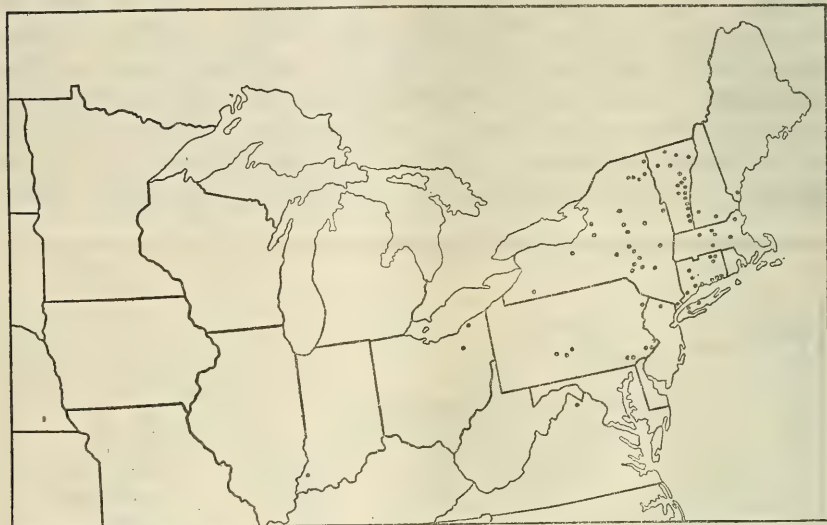


FIG. 5.—Outline map of the northeastern part of the United States, showing the known distribution of white-pine blister rust in North America to and including 1911.



FIG. 6.—Outline map of the northeastern part of the United States, showing (by black dots) the known distribution of white-pine blister rust in North America to and including 1912.

trip in 1811 with John Bradbury up the Missouri River to a point in the eastern part of Mercer County, N. Dak. His material must have been shipped quite promptly to England, as Fraser's nursery at

Chelsea, London, in 1813, offered for sale plants "collected in Upper Louisiana and principally on the River Missouri, North America." There is reason to believe that these were Nuttall's plants. The

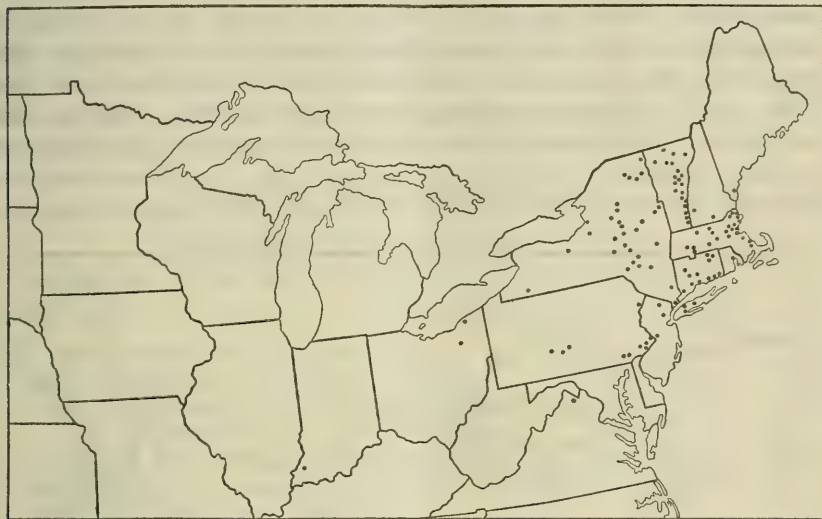


FIG. 7.—Outline map of the northeastern part of the United States, showing (by black dots) the known distribution of white-pine blister rust in North America to and including 1913.

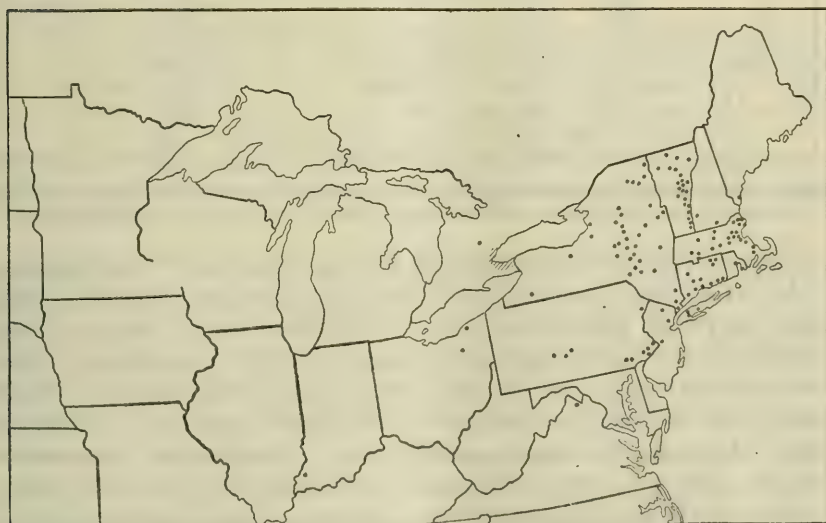


FIG. 8.—Outline map of the northeastern part of the United States, showing (by black dots and cross hatching) the known distribution of white-pine blister rust in North America to and including 1914. The cross hatching in this and the following maps indicates areas which are generally infected.

plant of interest to us is listed as *Ribes longiflorum*, a new species from the Missouri. This is now known as *R. odoratum* Wendland, which is the common form generally cultivated in the eastern United

States under the name *R. aureum*. This appears to be the form most common in cultivation in Europe, but the true *R. aureum* of the Rocky Mountain region and the plains of the Columbia was evidently introduced there soon after *R. odoratum*, if not at about the same time. Pursh may have referred to living plants of true *R. aureum* but we have no means of determining this. Lindley in 1828 made the new species *R. tenuiflorum* (now *R. aureum*) and says "Clt. 1812," evidently meaning "cultivated in 1812." He had this so definitely distinguished from our *R. odoratum* that his statement is fairly conclusive that *R. aureum* actually was introduced into England the same year as was *R. odoratum*. The agent introducing



FIG. 9.—Outline map of the northeastern part of the United States, showing (by black dots and cross hatching) the known distribution of white-pine blister rust in North America to and including 1915.

R. aureum can not be determined beyond question. There appears to be little doubt, because of the difficulty of communication at that time, that both plants were carried from their native regions to the eastern part of this country in the form of seeds. Cuttings may have been sent to Europe but it is more likely that seeds were sent. Seeds would not be likely to transmit a rust which does not attack the fruit. It does not seem possible that a fungus like *Cronartium ribicola* could be carried to Europe on these plants without becoming established in the Eastern States. Moreover, these species of *Ribes* apparently were introduced into Great Britain first. The fungus was not known in Great Britain until 1892, long after it was prevalent in other northern European countries. It appears that *Cronartium ribicola* was carried to Great Britain on infected white pines from northwestern Germany. The evidence appears to show that *Cro-*

nartium ribicola attacked *Ribes aureum* and *R. odoratum* after they reached Europe. Their susceptibility also indicates that they are not original hosts of the fungus.

Summing up the evidence available, it appears (1) that *Cronartium ribicola* is Asiatic in origin; (2) that it spread in the early 1800's into western Russia, whence it eventually spread well over Europe (41); (3) that it was brought to North America in young trees of *Pinus strobus*; and (4) that comparative studies (50) show that *Cronartium occidentale* is distinct.

HOSTS OF CRONARTIUM RIBICOLA.

Pines Infected and Likely to Become Infected.

Cronartium ribicola has attacked 11 of the white pines in the countries, Provinces, and States indicated in the following list:

Pinus aristata Engelm. in England (20a).

ayacahuite Ehrenb. in Scotland and England.³

cembra L. in Russia (58, 93), Switzerland (39, 40, 123, Germany (72, 77, 174, 177),

U. S. A. (Mass., Minn.).⁴

excelsa Wall. in Denmark (120), Germany (99), U. S. A. (Mass.).

flexilis James in Germany (173), Sweden,⁵ U. S. A. (Mass., Minn., Iowa).

koraensis Sieb. and Zucc. in Sweden.⁵

lambertiana Douglas in Belgium (101), Germany (62, 173).

monticola Douglas in Belgium (101), England (79), Germany (70).

parviflora Sieb. and Zucc. in U. S. A. (Mass.).

peuce Gris. in Germany (173).

strobus L. in Austria-Hungary (178), Belgium (70), Denmark (81, 115, 117, 119, 120), Finland (54, 83), Switzerland (40), France (70), Germany (70), Great Britain (111), Holland (70), Ireland (42), Norway (70), Russia (27, 58, 120), Siberia (161), Sweden (131⁵), Canada—Ontario (23, 56) and Quebec (107, 121), U. S. A. (Conn., Ind., Iowa, Maine, Mass., Mich., Minn., N. H., N. J., N. Y., Ohio, Penn., R. I., S. Dak., Vt., Va., Wis.). The fungus has occurred in a number of these States only on diseased pines shipped from outside points.

In every case the disease attacked these pines naturally in outbreak areas of Europe and North America and is not known to attack any of the pitch pines, although some of them have been present in infected areas. Whenever the other white pines are continuously exposed to the fungus they will be likely to develop the disease. The blister rust was first found on the different species of pines as follows:

Pinus strobus. Russia in 1854.

lambertiana. Germany in 1887.

cembra. Russia in 1890.

monticola. England in 1898.

excelsa. Denmark in 1902.

aristata. England in 1907.

Pinus ayacahuite. Great Britain in 1908.

flexilis. Germany in 1914.

peuce. Germany in 1914.

parviflora. United States in 1916.

koraensis. Sweden in 1920.

³ Communicated in a private letter from Dr. A. B. Borthwick, of Scotland.

⁴ The statements concerning occurrences in North America are based on records and specimens in the Office of Investigations in Forest Pathology.

⁵ Private letter from W. Stuart Moir, Office of Blister-Rust Control.

Sudworth (154) recognizes eight species of the white pines (exclusive of the piñon pines) for North America (fig. 2) but does not treat those of the Old World. Shaw (126), who treats the pines of the world, also recognizes eight North American species of white pines. He is, therefore, taken as the authority for the pines in this bulletin. The white pines of the world are grouped by Shaw as follows:

Genus *Pinus*.

Section Haploxylon.

Subsection Cembra.

Group I. Cembræ.

koraiensis +.

cembra +.

albicaulis.

Group II. Flexiles.

flexilis +.

armandi.

Group III. Strobi.

ayacahuite (or *strobiformis*) +.

lambertiana +.

parviflora +.

peuce +.

excelsa +.

monticola +.

strobis +.

Subsection Paracembra.

Group IV. Cembroides—piñon pines.

Group V. Gerardianæ—piñon pines.

Group VI. Balfourianæ.

balfouriana.

aristata +.

In examining the above synopsis, note the grouping of the known susceptible species (which are indicated by +) especially in the first three groups which make up the subsection Cembra. Investigations of outbreak areas in Europe where the various species of pine have been present might yield on this point most interesting and valuable information which can be obtained in no other way.

Inoculations of *Cronartium Ribicola* on Pines.

Klebahn (68, 71) appears to be the first European investigator who has inoculated pines with *Cronartium ribicola* and who has published his results. He inoculated young *Pinus strobus* trees with pycnospores, but with no success (70, p. 387). Inoculations made by him with sporidia in 1888 were rendered worthless because the pines were probably infected naturally before the test was made (71). On August 27, 1903, Klebahn (71) made inoculations on two young *Pinus strobus* trees by suspending telia-bearing leaves of *Ribes nigrum* above the trees and covering them with a large bell jar. On June 19,

1904, the pines were examined. At that time some of the new shoots bore abnormal leaves of a juvenile type singly, instead of in fives. The new twigs were abnormally pale in color. Many of the leaves of the growth of the previous year were spotted with yellow through their entire thickness. These yellow spots were especially plentiful near the base of the leaves. Microscopic examination showed abundant mycelium to be present in the yellow areas. Later pycnia developed on the twigs near the bases of the spotted leaves.

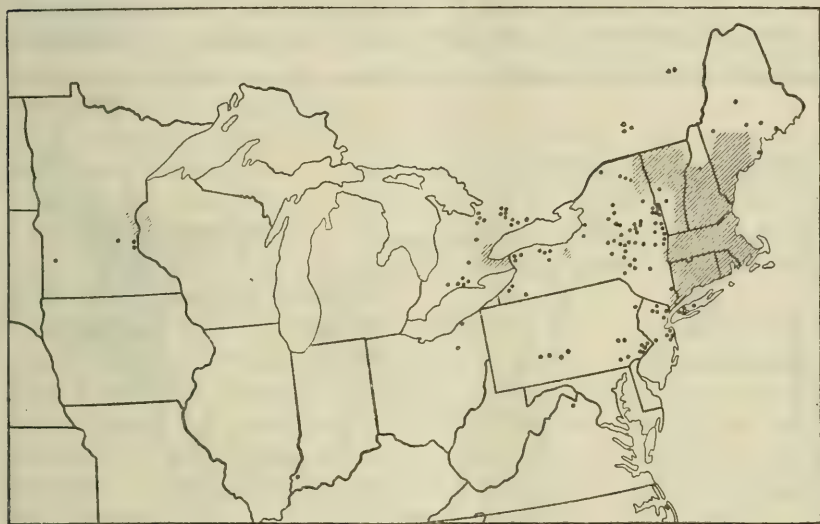


FIG. 10.—Outline map of the northeastern part of the United States, showing (by black dots and cross hatching) the known distribution of white-pine blister rust in North America to and including 1916.

In 1914, Tubeuf (174) inoculated trees of *Pinus strobus*, *P. lambertiana*, *P. cembra*, *P. cembroides*, *P. excelsa*, *P. peuce*, *P. parviflora*, *P. flexilis*, and *P. montezumae* with sporidia of *Cronartium ribicola* under controlled conditions. In 1917, æcia were produced on some of the *P. strobus*. Yellow spots were produced on the leaves of *P. lambertiana*, but no further development of the fungus occurred. Spots which were doubtfully caused by the fungus were noted on *P. cembroides*. No other species became infected. Infections were produced directly on the juvenile leaves, on mature leaves, and through the epidermis of the lengthening buds of the young shoots.

In North America, the writer seems to have been the first to inoculate successfully young *Pinus strobus* trees with sporidia (133, 134). The inoculations were made both with and without wounds in the young bark, telial columns being used for inoculum. Pycnial drops were produced by one tree unwounded and by one which was

wounded. At this stage slugs ate the infected bark and prevented further development of the fungus. In 1916 and in 1917, 150 æciospore inoculations were made on leaves, on twigs of various ages, and on branches of *P. strobus* trees up to six years. No infections have resulted.

Clinton and Miss McCormick (14, 15), have published details of successful inoculations, through the leaves, with sporidia on *P. strobus*. Inoculations were unsuccessful upon leaves of *P. excelsa*, *P. flexilis*, *P. koraiensis*, and *P. cembra*; also on the pitch pines *P. resinosa*, *P. sylvestris*, *P. densiflora*, and *P. austriaca*. Yellow spots



FIG. 11.—Outline map of the northeastern part of the United States, showing (by black dots and cross hatching) the known distribution of white-pine blister rust in North America to and including 1917.

have been secured on leaves of *P. lambertiana*, *P. pinea*, and *P. sabiniana*.

Cross-inoculations that are known to have been successful up to July 1, 1920, are shown in Plate I.

Species of *Ribes* That Have Been Infected Naturally.

In Europe and North America, where extensive outbreaks of *Cronartium ribicola* have occurred, a considerable number of species of *Ribes* have been found naturally infected by the fungus. Practically all of the cultivated species and most of the wild ones take the disease in every extensive outbreak area. More species have been found infected in Europe than in North America, because outbreaks have been discovered there in botanical gardens, parks, and nurseries

where extensive collections of the different species of *Ribes* were located, and hence more species have been subjected to attack.

In Europe the following species have become infected naturally: *Ribes aciculare* Smith, *R. affine* H. B. K., *R. alpinum* L., *R. americanum* Mill., *R. aureum* Pursh, *R. biebersteinii* hybrid, *R. bracteosum* Douglas, *R. cynosbati* L., *R. divaricatum* Douglas, *R. glandulosum* Grauer, *R. gordonianum* hybrid, *R. hirtellum* Michx., *R. irriguum* Douglas, *R. menziesii* Pursh, *R. missouriense* Nuttall, *R. multiflorum* Kit., *R. nigrum* L., *R. niveum* Lindl., *R. odoratum* Wendl., *R. oxycanthoides* L., *R. petraeum* Wulf., *R. reclinatum* L., *R. rotundifolium* Michx., *R. rubrum* L., *R. sanguineum* Pursh, *R. setosum* Lindl., *R. triste* Pallas, *R. vulgare* Lam.

The names of species of *Ribes* of North America are based on the treatment of the North American species by Coville and Britton in "North American Flora" (22) and of species of the other continents on that of Janczewski in "Monographie des Groseilliers, *Ribes* L." (60). For the sake of convenience the currants and gooseberries are kept in the single genus *Ribes*.

As recently as 1914 (136) the fungus had not been found in North America attacking any wild species of *Ribes*. Since then it has been found attacking an increasing number of wild *Ribes*, as additional species are subjected to infection by the spreading and multiplication of the known outbreak areas and as new ones are discovered. To date it is known to have been found attacking naturally the following species of *Ribes* in the States and Provinces named:

Ribes americanum (*floridum*).—Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, New York, Wisconsin, Minnesota, and Ontario.

cynosbati.—Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Wisconsin, Minnesota, and Ontario.

glandulosum (*prostratum*).—Maine, New Hampshire, Vermont, Massachusetts, Connecticut, New York, Wisconsin, Minnesota, and Ontario.

hirtellum.—Maine, New Hampshire, Massachusetts, New York, Wisconsin, and Minnesota.

irriguum.—New York.

lacustre.—Maine, New Hampshire, New York, and Wisconsin.

missouriense.—New York, Minnesota, and Wisconsin.

nigrum.—Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Wisconsin, Minnesota, Ontario, and Quebec.

odoratum.—Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, Minnesota, and Ontario.

reclinatum (*grossularia*).—Maine, Vermont, Massachusetts, New York, Wisconsin, Minnesota, and Ontario.

rotundifolium.—New York.

triste.—Maine, New Hampshire, Massachusetts, Wisconsin, Minnesota, and Ontario.

vulgare (*rubrum*).—Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, Wisconsin, Minnesota, and Ontario.

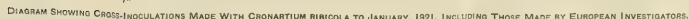
Inoculations of Cronartium ribicola on Ribes.

In 1888, Klebahn (63, 64) made the first known successful inoculations of this fungus on *Ribes*. Since that time a number of inoculations have been made in Europe by Klebahn (65, 66, 67, 68, 69, 70), Wettstein (70), Rostrup (118, 119, 120), Schøyen (124), Eriksson (31, 33), Tubeuf (167), Hennings (53), Sorauer (129), Tranzschel (92), Neger (100), Ewert (36, 37), Naumann (36), and Jaczewski (58, 59). The published accounts of most of these experiments are very fragmentary and lack many essential details. In fact the attitude of the European investigators seems to have been that of mild interest in a new fungus rather than that of intensive study of a new parasite and of the destructive disease caused by it.



FIG. 12.—Outline map of the northeastern part of the United States, showing (by black dots and cross hatching) the known distribution of white-pine blister rust in North America to and including 1918. For distribution to the end of 1919, see figure 2.

Since the summer of 1909 the writer and his collaborators have made repeated tests under controlled and natural conditions of all species and of all varieties of the cultivated species of *Ribes* that could be obtained. In the earlier work complete records were not kept, but in the last few years the records were made to cover all points likely to be of value. Hundreds of inoculations have been made on the more susceptible species to keep the fungus growing in vigorous condition, without records being made. It was felt that greenhouse tests alone were not dependable for susceptibility data. Therefore, in 1916, a test plat was located upon Block Island, R. I. This island lies 12 miles from the nearest projecting point of the mainland and 15 miles or more from the main shore line. No white pines are on the island and but few cultivated *Ribes*. It was chosen



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as the safest place for such work at that time. In midsummer, 1916, before the disease was fairly started on the bushes on the island, it was found to be pretty generally distributed over New England on *Ribes*, having plainly been widely disseminated there before the Block Island experiment was started. Conditions on the island are not very favorable for *Ribes* and are decidedly unfavorable for white pines. *Pinus nigra* var. *austriaca* is the only pine seen on the island, and it occurs only in protected hollows.

Table I presents the general results of tests made in the greenhouse where inoculations were made with both æciospores and urediniospores. A preliminary statement has been published, giving the earlier results of this work (147). This table is to be interpreted as follows:

In the columns headed "Susceptibility," a single cross (×) means slight infection, two crosses (××) mean a medium degree of infection, and three crosses (×××) mean heavy infection.

There are no means of knowing what degree of susceptibility was indicated by the experiments of European and Canadian investigators, whose results are included in section 1 of Table I. The foreign experimenters are first listed alphabetically under each species of *Ribes*, then the work done in this country is given in a similar manner. The varietal tests (sections 2 to 4 of Table I) are wholly the work of the Office of Investigations in Forest Pathology, there being practically no data in foreign literature on inoculations of horticultural varieties.

In numerous cases but a single test has been made as yet; but the general behavior of the tested plants in the spread of the fungus, the type of its fruiting, etc., during the rest of the season are considered in the final estimate of susceptibility. When a single test has been made under favorable conditions, it is believed that the results are fairly indicative of the susceptibility of the species or variety tested. Many tests were made under conditions known to be adverse, and the negative results are largely due to this cause alone. But these tests are given with the others to give some idea of what has been done. Scanty numbers of tests are often due to the *Ribes* stock dying before a second test could be made. This is true of many cuttings which made a weak start and did not survive potting.

In sections 2 to 4 of Table I, relating to the varieties of *Ribes*, an attempt has been made to use varietal names that are intelligible to horticulturists as accepted by the American Pomological Society. Acknowledgment is made to the Office of Horticultural and Pomological Investigations of the United States Department of Agriculture for help in this matter. In some cases varietal names are given which are considered to be synonyms of others in the list; but in such cases the stocks used under the two names were evidently different. Varieties and even species of *Ribes* supplied by nurserymen are often other than what they purport to be, and in some cases they are mixtures of two or more distinct things; hence, the varietal names can not be taken as being absolutely reliable.

TABLE I.—Results of inoculations made on various species and horticultural varieties of *Ribes*, showing data on susceptibility in the greenhouse and out of doors on Block Island, R. I.

Species or variety and investigators.	Inoculations.		Susceptibility.		Species or variety and investigators.	Inoculations.		Susceptibility.	
	Infection.	Number.	In the greenhouse.	Out of doors.		Infection.	Number.	In the greenhouse.	Out of doors.
SEC. 1.—Species of <i>Ribes</i> . ^a					SEC. 1.—Species of <i>Ribes</i> —Contd.				
<i>R. alpestre</i> :					<i>R. diacantha</i> :				
Gravatt.....	2	2	XX	XX	Gravatt.....	1	2	X	-----
<i>R. alpinum</i> :					Taylor.....	0	2		
Klebahn.....	1	1	-----	-----	<i>R. divaricatum</i> :				
Neger.....	0	1	-----	-----	Rostrup.....	1	1	-----	-----
Sorauer.....	1	1	-----	-----	Tubeuf.....	1	1	-----	-----
Gravatt.....	0	1	0	0	Gravatt.....	11	18	XX	XX
Marshall.....	0	2			Spaulding.....	3	3		
Taylor.....	0	2			Taylor.....	2	2		
<i>R. alpinum macrophyllum</i> :					<i>R. erythrocarpum</i> :				
Rhoads.....	0	1	0	-----	Gravatt.....	2	2	XX	-----
Spaulding.....	0	1			<i>R. fasciculatum</i> :				
<i>R. amarum</i> :					Gravatt.....	4	4	XX	X
Taylor.....	1	1	XXX	-----	Merrill.....	1	2		
<i>R. americanum</i> :					Spaulding.....	1	3		
Sorauer.....	1	1	-----	-----	Taylor.....	20	20	-----	-----
Gravatt.....	4	4	XX	XX	<i>R. fasciculatum chinense</i> :				
Spaulding.....	2	2			Gravatt.....	1	1	X	-----
Taylor.....	6	6			Merrill.....	1	3		
York.....	1	1			Spaulding.....	6	6		
<i>R. aureum</i> :					<i>R. fasciculatum japonicum</i> :				
Klebahn.....	4	4	-----	-----	Spaulding.....	2	2	XX	-----
Sorauer.....	1	1	-----	-----	<i>R. fontanum</i> :				
Tubeuf.....	1	1	-----	-----	Colley and Taylor.....	1	1	XX	-----
Gravatt.....	13	13	XX	XX	Gravatt.....	1	1		
Hedgecock.....	1	1			<i>R. fontenayense</i> :				
Marshall.....	5	6			Gravatt.....	3	3	X	X
Spaulding.....	6	6			<i>R. futurum</i> :				
Taylor.....	27	28	-----	-----	Gravatt.....	1	1	XX	-----
<i>R. aureum "palmarum foeminum"</i> :					Merrill.....	1	1		
Spaulding.....	1	2	XX	-----	Spaulding.....	1	1		
<i>R. auren X reclinaum</i> :					Taylor.....	1	1	-----	-----
Gravatt.....	1	1	X	-----	<i>R. giraldii</i> :				
<i>R. bethmontii</i> :					Gravatt.....	1	1	XX	-----
Spaulding.....	1	2	XX	-----	<i>R. glandulosum</i> :				
<i>R. bracteosum</i> :					Lyman.....	1	1	XX	-----
Gravatt.....	3	4	XX	X	Snell.....	6	6		
<i>R. carrierei</i> :					Spaulding.....	1	1		
Gravatt.....	10	11	XX	XX	Taylor.....	2	2	-----	-----
<i>R. cereum</i> :					<i>R. glutinosum</i> :				
Gravatt.....	2	2	XX	X	Gravatt.....	1	3	X	-----
Marshall.....	2	2			Spaulding.....	2	2		
Spaulding.....	6	7			<i>R. gordonianum</i> :				
Taylor.....	2	3			Gravatt.....	3	4	XX	XX
<i>R. coloradense</i> :					Spaulding.....	1	1	XX	-----
Spaulding.....	1	1	XX	-----	<i>R. hesperium</i> :				
Taylor.....	2	2	-----	-----	Gravatt.....	1	2	XX	-----
<i>R. cruentum</i> :					Merrill.....	1	1		
Gravatt.....	5	7	XX	-----	Taylor.....	1	1		
<i>R. culverwellii</i> :					<i>R. hirtellum</i> :				
Gravatt.....	3	4	XX	X	Gravatt.....	7	11	XX	X
Marshall.....	3	3	-----	-----	Lyman.....	2	2		
<i>R. curvatum</i> :					Spaulding.....	2	4		
Gravatt.....	1	4	XX	XX	Taylor.....	2	3	-----	-----
Marshall.....	1	3			<i>R. hirtellum X reclinaum</i> :				
Spaulding.....	1	1			Hedgecock.....	2	2	X	-----
Taylor.....	1	1			<i>R. holosericeum</i> :				
<i>R. cynosbati</i> :					Gravatt.....	1	1	XX	-----
Tubeuf.....	1	1	-----	-----	<i>R. inebrians</i> :				
Gravatt.....	3	4	XX	-----	Hedgecock.....	4	4	X	-----
Hedgecock.....	1	1			<i>R. inerme</i> :				
Lyman.....	2	3			Gravatt.....	15	17	XX	-----
Spaulding.....	2	2			Hedgecock.....	2	2		
					Spaulding.....	2	3		
					Taylor.....	4	4	-----	-----

^a Summary of tests made in foreign countries and in America.

TABLE I.—Results of inoculations made on various species and horticultural varieties of *Ribes*, etc.—Continued.

Species or variety and investigators.	Inoculations.		Susceptibility.		Species or variety and investigators.	Inoculations.		Susceptibility.	
	Infection.	Number.	In the greenhouse.	Out of doors.		Infection.	Number.	In the greenhouse.	Out of doors.
SEC. 1.—Species of <i>Ribes</i> —Contd.					SEC. 1.—Species of <i>Ribes</i> —Contd.				
<i>R. innominatum</i> :					<i>R. nigrum</i> "fasciculatum":				
Spaulding.....	1	4	} XX		Rhoads.....	1	1	} XXX	
Taylor.....	2	2			<i>R. nigrum</i> "folioargentea":				
<i>R. irriguum</i> :					Spaulding.....	1	1	} XXX	
Gravatt.....	2	2	X	X	Taylor.....	2	2		
<i>R. lacustre</i> :					<i>R. nigrum</i> "laciniatum":				
Gravatt.....	8	11	} XX	X	Sorauer.....	1	1	}	
Spaulding.....	2	2			<i>R. odoratum</i> :				
Taylor.....	3	3			Gravatt.....	25	29	} XX	XX
<i>R. leptanthum</i> :					Hedgecock.....	6	6		
Gravatt.....	4	5	} b X	.....	Marshall.....	1	2		
Spaulding.....	1	1			Spaulding.....	3	3		
Taylor.....	4	7			Taylor.....	15	15		
<i>R. lobbi</i> :					<i>R. oxyacanthoides</i> :				
Gravatt.....	2	4	X	X	Tubeuf.....	0	1	}	
<i>R. malvacum</i> :					Gravatt.....	2	2		
Gravatt.....	1	4	} X	.....	Lyman.....	0	1		
Spaulding.....	0	3			Merrill.....	1	1		
<i>R. malvacum viridifolium</i> :					Spaulding.....	1	1	} XX	
Gravatt.....	1	4	} X	.....	Taylor.....	2	2		
Merrill.....	1	2			<i>R. parishii</i> :				
Spaulding.....	0	3			Taylor.....	7	7	} XX	
<i>R. menziesii</i> :					<i>R. petraeum</i> :				
Gravatt.....	1	1	} XX	X	Gravatt.....	2	3	} XX	
Taylor.....	4	4			Spaulding.....	1	1		
<i>R. missouriense</i> :					<i>R. petraeum atropurpureum</i> :				
Rostrup.....	1	1	} XX	X	Gravatt.....	1	1	} XX	
Gravatt.....	1	1			<i>R. reclinatum</i> :				
Lyman.....	1	1			Jaczewski.....	0	1	}	
Spaulding.....	1	1			Klebahn.....	1	1		
Taylor.....	3	3			Schayen.....	1	1		
<i>R. missouriense</i> × <i>reclinatum</i> :					Sorauer.....	0	1		
Gravatt.....	2	3	X		Tubeuf.....	1	1	}	X
<i>R. montigenum</i> :					Gravatt.....	4	4		
Spaulding.....	1	1	X		Hedgecock.....	1	1		
<i>R. multiflorum</i> :					Spaulding.....	1	1		
Rostrup.....	1	1	} X		<i>R. reclinatum grafted on R. aureum</i> :				
Rhoads.....	0	1			Klebahn.....	6	7	} X	
Spaulding.....	1	1			<i>R. reclinatum</i> × <i>missouriense</i> :				
<i>R. nevadense</i> :					Gravatt.....	2	2	} XX	XX
Gravatt.....	0	1	} XX	.....	<i>R. reclinatum</i> × <i>rotundifolium</i> :				
Spaulding.....	2	2			Gravatt.....	1	1	} X	
<i>R. nigrum</i> :					<i>R. robustum</i> :				
Eriksson.....	18	18	} XXX	XXX	Spaulding.....	1	2	} XX	
Ewert.....	6	6			Taylor.....	2	2		
Hennings.....	1	1			<i>R. roezli</i> :				
Klebahn.....	11	12			Gravatt.....	0	1	} X	
Jaczewski.....	1	1			Taylor.....	1	1		
McCubbin.....	3	4			<i>R. rotundifolium</i> :				
Naumann.....	1	1			Sorauer.....	1	1	}	
Rostrup.....	1	1			Gravatt.....	1	1		
Sorauer.....	1	1			Spaulding.....	0	8		
Tranzschel.....	1	1			Taylor.....	6	6		
Tubeuf.....	2	2			<i>R. rubrum</i> :				
Gravatt.....	29	36			Jaczewski.....	0	1	}	X
Hedgecock.....	3	3			Klebahn.....	1	1		
Marshall.....	3	3			Neger.....	0	1		
Merrill.....	5	5			Rostrup.....	1	1		
Spaulding.....	8	8			Sorauer.....	1	1	}	
Taylor.....	11	21			Gravatt.....	1	1		
York.....	1	1			Spaulding.....	0	8		
<i>R. nigrum</i> "aconitifolium":					Taylor.....	6	6		
Spaulding.....	1	1	} XX		<i>R. rubrum</i> :				
<i>R. nigrum</i> "crispum":					Jaczewski.....	0	1	}	
Sorauer.....	1	1			Klebahn.....	1	1		
					Neger.....	0	1		
					Rostrup.....	1	1		
					Sorauer.....	1	1		

b Slight.

c Part seedling plants.

TABLE I.—Results of inoculations made on various species and horticultural varieties of *Ribes*, etc.—Continued.

Species or variety and investigators.	Inoculations.		Susceptibility.		Species or variety and investigators.	Inoculations.		Susceptibility.	
	Infection.	Number.	In the greenhouse.	Out of doors.		Infection.	Number.	In the greenhouse.	Out of doors.
SEC. 1.—Species of <i>Ribes</i> —Contd.					SEC. 2.—Varieties of <i>Ribes nigrum</i> .				
<i>R. rubrum</i> "petrow-alskyanum":					Bang up:				
Spaulding.....	0	1	X		Gravatt.....	1	1	X	.....
Spaulding and Merrill.....	1	1			Beauty:				
<i>R. rubrum pubescens</i> :					Spaulding.....	1	1	XXX	.....
Spaulding.....	1	2	X		Black Dutch:				
<i>R. rubrum scandicum</i> :					Gravatt and Taylor.....	5	5	XXX	.....
Merrill.....	2	2	XX		"Black English":				
Rhoads.....	1	1			Colley, Gravatt, Spaulding, and Taylor.....	14	14	XX	.....
Spaulding.....	1	1			Black Grape:				
Taylor.....	1	1			Spaulding.....	1	1	X	.....
<i>R. rubrum "sibiricum"</i> :					Blacksmith:				
Spaulding and Merrill.....	2	3	X		Gravatt.....	3	3	XX	.....
<i>R. sanguineum</i> :					Black Victoria:				
Neger.....	1	1			Gravatt, Marshall, and Spaulding.....	24	27	XX	XXX
Sorauer.....	1	1			Boskoop:				
Tubeuf.....	1	1			Colley, Spaulding, and Taylor.....	5	8	XX	XX
Gravatt.....	4	6	X		Carter:				
Spaulding.....	4	4			Gravatt.....	4	4	XX	XX
Taylor.....	1	1			"Cassis à fruit noir":				
<i>R. sanguineum "albium"</i> :					Gravatt.....	2	2	XX	XX
Gravatt.....	6	6	XX	XX	Champion:				
<i>R. sanguineum "floro pleno"</i> :					Hedgecock, Marshall, and Spaulding.....	5	5	XXX	XX
Gravatt.....	1	1	X	X	Climax:				
Marshall.....	2	4			Gravatt, Marshall, and Spaulding.....	14	14	XXX	XXX
<i>R. setosum</i> :					Clipper:				
Sorauer.....	1	1			Gravatt.....	2	2	XX	XX
Gravatt.....	3	4	X		Collins:				
Spaulding.....	1	1			Spaulding.....	1	1	X	.....
<i>R. speciosum</i> :					Coronation:				
Gravatt.....	3	7	XX	X	Gravatt and Taylor.....	3	3	XX	.....
Spaulding.....	1	1			Eagle:				
<i>R. sterilis</i> :					Gravatt and Spaulding.....	13	13	XX	XX
Spaulding.....	0	2	0		Eclipse:				
<i>R. succirubrum</i> :					Spaulding.....	2	2	X	.....
Gravatt.....	1	2	XX	XX	Edina:				
Spaulding.....	0	1			Gravatt.....	4	4	XXX	.....
Taylor.....	1	1			Ethel:				
<i>R. tenue</i> :					Spaulding and Taylor.....	2	2	X	.....
Gravatt.....	1	1	XXX		"French Black":				
Spaulding.....	0	1			Gravatt and Spaulding.....	4	4	XX	XX
<i>R. transbaicalis</i> :					Kerry:				
Spaulding and Merrill.....	1	1	X		Gravatt.....	4	5	XX	XX
<i>R. triste</i> :					Lee:				
Spaulding.....	7	7	XX	X	Gravatt, Marshall, and Spaulding.....	14	16	XX	XXX
Taylor.....	0	1			Magnus:				
<i>R. viburnifolium</i> :					Gravatt.....	4	5	XXX	XXX
Taylor.....	5	5	X		Mammoth:				
<i>R. villosum</i> :					Gravatt.....	2	2	XX	XXX
Gravatt.....	0	4	0		Marvel:				
<i>R. viscosissimum</i> :					Gravatt, Spaulding, and Taylor.....	6	6	X	.....
Gravatt.....	3	3	XX		Naples:				
<i>R. vulgare</i> :					Marshall and Taylor.....	4	5	XXX	XXX
Schøyen.....	1	1			Norton:				
Hedgecock.....	3	3	X		Gravatt.....	-1	1	X	.....
Spaulding.....	1	1							
<i>R. vulgare macrocarpum</i> :									
Spaulding.....	1	1	X						
<i>R. wolffi</i> :									
Spaulding.....	2	2	XX						

b Slight.

TABLE I.—Results of inoculations made on various species and horticultural varieties of *Ribes*, etc.—Continued.

Species or variety and investigators.	Inoculations.		Susceptibility.		Species or variety and investigators.	Inoculations.		Susceptibility.	
	Infection.	Number.	In the greenhouse.	Out of doors.		Infection.	Number.	In the greenhouse.	Out of doors.
SEC. 2.—Varieties of <i>Ribes nigrum</i> —Con.					SEC. 3.—Varieties of <i>Ribes vulgare</i> —Con.				
Ontario:					Everybody's:				
Gravatt.....	2	2	XX	-----	Gravatt.....	6	6	X	X
Saunders:					"Eyeth Nova":				
Gravatt and					Merrill and				
Spaulding.....	6	9	XX	XXX	Spaulding.....	0	3	0	-----
Seabrook:					Fay:				
Spaulding.....	3	3	XXX	-----	Gravatt.....	1	1	X	XX
Standard:					Filler:				
Spaulding.....	1	1	X	-----	Gravatt.....	5	5	X	X
Success:					Fox Red:				
Spaulding.....	1	1	X	-----	Gravatt.....	4	4	X	X
Topsy:					Franco-German:				
Gravatt.....	2	2	XX	-----	Gravatt, Mar-				
Wales:					shall and				
Spaulding.....	1	1	XX	-----	Spaulding.....	0	21	0	b X
Winona:					Frauentorf:				
Spaulding.....	1	2	X	-----	Gravatt.....	2	2	X	-----
Woods:					"Giant Red":				
Gravatt.....	4	4	XXX	-----	Gravatt and				
SEC. 3.—Varieties of <i>Ribes vulgare</i> .					Marshall.....	8	10	X	X
Admirable:					"Giant White":				
Spaulding and					Gravatt.....	4	4	X	X
Taylor.....	3	3	XX	-----	Goliath:				
Albert:					Spaulding and				
Gravatt and					Taylor.....	2	2	X	-----
Marshall.....	4	18	X	X	Greenfield:				
Angers:					Spaulding and				
Merrill and					Taylor.....	2	4	X	-----
Spaulding.....	3	3	X	-----	Holland:				
Bertin:					Gravatt.....	0	5	0	b X
Gravatt.....	2	2	X	-----	Imperial:				
"Blanc de Werden":					Gravatt.....	2	2	X	-----
Gravatt.....	4	4	X	-----	"Improved Cherry":				
Bonum:					Gravatt.....	6	6	X	XX
Gravatt.....	6	6	X	-----	Knight:				
Brandenburg:					Gravatt, Spaul-				
Spaulding.....	2	2	XX	-----	ding, and Tay-				
Buddins:					lor.....	5	6	XX	-----
Gravatt.....	2	2	X	-----	"Large Red":				
"Champagne White":					Spaulding and				
Spaulding.....	1	1	X	-----	Merrill.....	2	3	X	-----
Chautauqua:					"Large White":				
Gravatt and					Gravatt.....	4	5	XX	XX
Marshall.....	7	7	X	XX	London:				
Chenonceaux:					Gravatt and	20	22	b X	b X
Gravatt and					Marshall.....				
Merrill.....	5	5	X	-----	"Marvin Crystal":				
Cherry:					Rhoads.....	1	1	X	-----
Marshall.....	1	1	-----	X	Moore Ruby:				
Comet:					Gravatt, Hedg-				
Marshall.....	2	2	-----	X	cock, and Mar-				
"Commun Blanc":					shall.....	9	10	X	X
Gravatt.....	4	4	X	-----	New Red Dutch:				
Conde:					Spaulding.....	1	1	XXXX	-----
Spaulding.....	1	1	X	-----	North Star:				
Constant:					Colley and Tay-				
Gravatt.....	3	5	X	-----	lor.....	0	1	0	XX
Crawford:					Norway:				
Gravatt.....	2	2	X	-----	Gravatt.....	5	5	XX	XX
Cumberland:					Palluau:				
Gravatt and					Gravatt, Spaul-				
Spaulding.....	5	5	X	0	ding and Taylor	5	6	XX	XX
Dilnot:					Perfection:				
Gravatt and					Marshall.....	1	1	X	X
Taylor.....	3	3	X	-----	Raby Castle:				
Diploma:					Spaulding.....	2	2	X	-----
Gravatt.....	6	7	X	X	Red Dutch:				
Early Scarlet:					Spaulding and				
Merrill and					Taylor.....	2	2	X	X
Spaulding.....	2	2	XXX	-----	"Red English":				
					Spaulding.....	1	2	X	-----
					Red Grape:				
					Gravatt.....	3	3	X	-----

†Slight.

TABLE I.—Results of inoculations made on various species and horticultural varieties of *Ribes*, etc.—Continued.

Species or variety and investigators.	Inoculations.		Susceptibility.		Species or variety and investigators.	Inoculations.		Susceptibility.	
	Infection.	Number.	In the greenhouse.	Out of doors.		Infection.	Number.	In the greenhouse.	Out of doors.
SEC. 3.—Varieties of <i>Ribes vulgare</i> —Con.					SEC. 4.—Varieties of <i>Ribes reclinatum</i> .				
Redpath:					Achilles:				
Spaulding.....	0	1	0	-----	Spaulding.....	0	1	0	-----
Rivers:					Alma:				
Gravatt.....	4	4	(d)	-----	Rhoads and Taylor.....	1	3	×	-----
Sablons:					Berkeley:				
Spaulding and Taylor.....	1	2	×	-----	Gravatt and Marshall.....	5	6	×	×
Scotch:					Carmen:				
Gravatt, Merrill and Spaulding.....	3	5	×	-----	Gravatt.....	5	5	×	×
Simcoe King:					Carrie:				
Spaulding.....	0	1	0	-----	Marshall and Taylor.....	4	5	×	×
Skinner:					Champion:				
Gravatt.....	2	2	×	×	Gravatt and Taylor.....	1	2		-----
Striatum:					Chautauqua:				
Spaulding.....	1	1	×	-----	Spaulding.....	1	1	×	-----
Transparent:					Columbus:				
Gravatt.....	10	10	×	×	Spaulding.....	4	4		×
Turinoise:					Cumberland:				
Gravatt and Taylor.....	5	5	×	-----	Gravatt and Spaulding.....	2	3	×	-----
Utrecht:					Downing:				
Gravatt.....	2	2	×	0	Gravatt and Spaulding.....	2	4	0	×
Verrieres:					Duncan:				
Gravatt and Spaulding.....	4	4	×	-----	Merrill and Taylor.....	2	2	×	-----
Versaille:					Golden Prolific:				
Gravatt, Marshall and Spaulding.....	6	7	×	×	Gravatt.....	6	11	×	×
Victoria:					Houghton:				
Gravatt, Spaulding and Taylor.....	6	6	×	×	Gravatt and Spaulding.....	2	12	×	×
Warner:					Industry:				
Gravatt.....	2	2	×	-----	Gravatt.....	2	2	×	×
Wentworth:					Josselyn:				
Spaulding.....	1	1	×	-----	Spaulding.....	0	3	0	×
"Wentworth White":					Keepsake:				
Gravatt.....	2	3	×	-----	Gravatt.....	4	6	×	×
"White Barle Duc":					Lancashire Lad:				
Marshall.....	0	1	-----	×	Gravatt.....	2	2	×	×
"White Brandenburg":					Mabel:				
Spaulding.....	0	1	0	-----	Spaulding.....	0	2	0	-----
White Champion:					Mountain:				
Gravatt.....	3	3	×	-----	Gravatt and Spaulding.....	3	7	×	×
White Cherry:					Oregon:				
Spaulding.....	1	1	×	-----	Gravatt and Taylor.....	2	7	×	×
White Dutch:					Pearl:				
Gravatt and Marshall.....	4	4	-----	×	Gravatt and Taylor.....	5	6	×	×
White Gondouin:					Poorman:				
Gravatt and Marshall.....	5	5	×	×	Gravatt.....	2	3	×	×
White Grape:					Portage:				
Marshall.....	11	11	-----	×	Gravatt.....	4	4	×	×
White Imperial:					Smith:				
Gravatt, Hedgcock and Taylor.....	4	5	×	×	Marshall and Spaulding.....	3	3	×	×
"White Kaiser":					Transparent:				
Spaulding.....	1	1	×	-----	Gravatt and Marshall.....	5	6	×	×
"White Leviathan":					Triumph:				
Gravatt and Merrill.....	5	5	×	-----	Gravatt, Hedgcock and Spaulding.....	9	10	×	×
White Pearl:					Van Fleet:				
Spaulding.....	1	1	×	-----	Gravatt.....	2	2	×	×
White Versailles:					Victoria:				
Merrill and Taylor.....	1	2	0	-----	Gravatt.....	1	1	×	-----
Wilder:					White Lion:				
Spaulding.....	2	2	-----	×	Marshall.....	1	1	-----	×
Wilson:					Whitesmith:				
Marshall.....	1	1	-----	×	Gravatt.....	2	3	×	×

a Dead spots only.

Recently Thayer (159) and Bunyard (8) have published results of their studies of the cultivated red and white currants. They find these currants to be of mixed and badly confused parentage, but conclude that certain varieties sprang from each of the three species, *Ribes vulgare*, *R. rubrum*, and *R. petraeum*. Many varieties are still to be assigned to the proper species; hence, they are grouped in Table I under the name *R. vulgare*, for convenience, as it is yet impossible to assign all of them to any species.

The gooseberries are well known to be in many cases a mixture of *Ribes reclinatum* with several American species or even pure selections of American species. For convenience they are grouped under the species name, *R. reclinatum*.

Susceptibility of *Ribes* Species and Varieties to *Cronartium ribicola*.

Estimates of the susceptibility of the various species and varieties of *Ribes* have been made. (See Table I.) These are based on work done in the greenhouse and on results of the experiments out of doors on Block Island. These estimates have been made mostly by two persons, so that they are believed to be quite reliable and accurate by the standards chosen. The estimates for the inside experiments were made entirely independent of those out of doors. The two agree surprisingly. They are based on the results of work covering several years, but many of the species and varieties have been subjected to infection but a single year. A few species will be noted which have remained immune in our tests. But some of these species are known to have become infected elsewhere. This is true of *Ribes alpinum* which is reported to take this disease in Europe, although it is entirely resistant in North America (35, 53). *Ribes innominatum* has been well tested and took the disease only on newly developed leaves. It is a very resistant species. *Ribes sterilis*, *R. tenue* and *R. villosum* have not yet undergone satisfactory tests, so that no conclusive statement concerning them can be made.

The species of *Ribes* vary in susceptibility from the extremely susceptible *Ribes nigrum* to the very resistant *R. leptanthum*. On the former are produced the maximum number of uredinia and telia of the largest size, while on the latter the minimum number is produced and these are poorly developed. *Ribes alpinum* has been entirely immune with us, although it takes the disease in Europe.

The varieties of a cultivated species run fairly true to the species as a whole. Some real variation among varieties is believed to depend upon their mixed parentage. Many tests were necessarily made when the plants were not at the most favorable stage of development for the fungus to attack, and it is likely that further tests of aberrant varieties may bring most of them back into agreement with the species to which they belong. Of the varieties of the cultivated red currants

which have been tested, the following are nearly immune: Eyath Nova, Franco-German, Holland (see also Tubeuf, 174), London, Rivers, Simcoe King. That is, plants tested under these names have so far shown themselves resistant, but not entirely immune.

The cultivated gooseberries, varieties of *Ribes reclinatum* in some cases more or less mixed with American species of gooseberries, are resistant but occasionally will become infected.

Resistant species and varieties have been found reacting to the fungus and affecting it as follows:

- (1) Decreased number of uredinia and telia.
- (2) Above accompanied by reduction in size of uredinia and telia with lowered viability.
- (3) Small streaks and flecks of dead or dying tissue in infected leaves with uredinia and telia. (See Pl. V, fig. 1.)
- (4) Small dead spots formed early with very few or no uredinia and telia. (See Pl. V, figs. 3 and 4.)

This agrees essentially with the results of Stakman (149) with *Puccinia graminis* on resistant grains.

LIFE HISTORY OF CRONARTIUM RIBICOLA.

The Peridermium Stage on Pines.

THE INCUBATION PERIOD ON PINES.

According to European investigators, *Cronartium ribicola* has an indeterminate incubation period between infection of pine and production of æcia. This varies from about two to four years, and possibly much longer. In one of Klebahn's inoculation experiments he got pycnial drops on young white pines 11 months after the inoculation (71). In another instance, infection probably occurred in 1887, pycnia were produced in 1888, and æcia in 1889 (65). Recently Tubeuf (174) reported the results of successful inoculations on *Pinus strobus*. Inoculations were made on September 11, 1914; pycnia formed in July, 1915; they were also produced in 1916 in May and thereafter; æcia appeared in April, 1917.

In North America considerable attention has been given to this matter. McCubbin (84) first attacked it by extensive studies of naturally infected trees. He concluded that five seasons were necessary for most of nearly 1,600 infections in Ontario to develop mature æcia. He outlines the process as follows: first season, infection occurs; second season, dormant; third season, swelling of the bark; fourth season, swelling with pycnia; fifth season, mature æcia. This makes a lapse of about three years and six months between actual infection and the formation of mature æcia.

Stone (153) in 1917 studied this problem in a locality where the fungus was fruiting on white pines for the first time after infection occurred. The infection came from *Ribes cynosbati*, which in 1914 was heavily infected. The *Ribes* plants were removed in the spring

of 1915, so that infection was limited to the season of 1914. Of 40 infections found, 12 were on 1913 wood and produced æcia in May, 1917; 28 were on 1914 wood and produced æcia in May, 1917. The period of incubation for the former cases could not be more than three years and nine months. It may be that infection took place on 1-year-old wood, in which case the incubation period would be only two years and ten months, as was the case with the 28 infections on 1914 wood.

Study of infected branches which had just borne æcia for the first time was made by Posey and Gravatt in 1917 at Stratham, N. H. Their notes show that more than 99 per cent of these infections might be 3 years and 6 months old, but could be no older. In another locality, they found a number of æcia upon growth of the year 1915, making an incubation period of about 18 months.

The first successful inoculations of pines with sporidia of *Cronartium ribicola* are apparently those made by Klebahn on August 27, 1903 (71). *Ribes nigrum* leaves with telia were placed over two young trees of *Pinus strobus* and the whole covered with bell jars as long as the *Ribes* leaves remained fresh. On June 19, 1904, these trees had swollen twigs bearing juvenile leaves. Early in July, pycnial drops formed, after a lapse of 10 months. It is probable that in the normal course of events æcia would form the next May. This would make an incubation period of about 19 months.

The writer (133) in November, 1910, inoculated a number of healthy *Pinus strobus* trees in the greenhouse with teliospores. These inoculations were made on the young bark. In January, 1912, one each of those inoculated with wound and without wound of bark developed marked swelling. A little later pycnial drops formed, but snails ate them and the surrounding bark, so that the infections did not develop. Apparently it would have been a matter of but a few months when æcia would have formed. This would give an incubation period of about two years. In May, 1916, the writer (145) set out healthy *Pinus strobus* trees among some experimental *Ribes* bushes on Block Island, R. I. The *Ribes* were heavily infected the rest of the season. Telia began to form the latter part of July and were abundant by September. On May 10, 1918, several of these trees were found bearing æcia. This makes a maximum incubation period of about 21 months.

In 1917, 10 young plants of *Pinus flexilis* were set out in the experimental plat on Block Island. Nine of them have lived. In the spring of 1920 seven of them bore æcia of *Cronartium ribicola* on the growth of 1918, and the other two were much swollen and discolored, so that if alive they will certainly produce æcia in 1921. It appears that *P. flexilis* is very susceptible. The experiments on Block Island indicate that it is even more susceptible than is *P. strobus*. The incubation

period would be about 20 months. A number of *P. strobus* trees set in 1917 also bore æcia in 1920, and many more will do so in 1921.

Clinton and McCormick (12, 15) found that artificially infected trees of *Pinus strobus*, kept in the greenhouse, developed pycnial drops in five to six months after inoculation.

All of the writer's experience in various outbreaks of this parasite shows that most of the newly formed æcia are located on nodes and internodes that are 3 years old or over. It is rather exceptional for æcia to be borne on needle-bearing wood 2 years old, in which case the minimum incubation period is about 18 months. The average incubation period out of doors is approximately 3 years and 6 months.

TIME, PLACE, AND MANNER OF INFECTION OF PINES.

There is constant danger of infection of pines at any time after telia form; that is, after about the 1st of June. The teliospores produce sporidia in 6 hours under favorable conditions.⁶ The sporidia germinate immediately. According to Clinton and Miss McCormick, infection of pine leaves may take place within 48 hours (14, 15) after the germinating sporidia are placed on the leaves. Any period of moist weather of 54 hours or longer after about June 1 may cause infection of pines.

The available evidence indicates that infection of pine twigs takes place in or about the bases of the leaf fascicles (71, 84). If this is true for most cases, as seems likely, infection of *Pinus strobus* can occur only on wood that is 1 or 2, or exceptionally, 3 or 4 years old. This follows from the fact that the needles of this species ordinarily live only two seasons, but rather exceptionally they may live three or four seasons.

Tubeuf (174) in 1917 published the results of successful inoculations with sporidia of *Cronartium ribicola* on pines. He inoculated *Pinus strobus*, *P. lambertiana*, *P. excelsa*, *P. parviflora*, *P. peuce*, *P. cembroides*, *P. flexilis*, *P. montezumae*, and *P. cembra*. He got yellow spots on the needles of *P. lambertiana* but no further results were noted. *P. strobus* became infected readily and bore æcia, but none of the other species showed definite signs of infection. Infection evidently occurred in the needles, many of them having yellow spots. They were also present on the stems. Mycelium was abundant in the yellow areas. Tubeuf says that infection of the stem from the leaves is not common, but that direct infection of the stems is much more likely to occur. No pycnia were obtained on leaves, although the masses of mycelium in the yellow spots seemed to form the base for the pycnial spots in the bark. Older plants of *Pinus strobus* became infected less readily than those only 2 years old. This

⁶ York, H. H. Field studies of *Cronartium ribicola* in the White Mountains of New Hampshire. Seen in manuscript. To be published in Phytopathology.

infection of young plants he attributes to the fact that shoots bearing primary (juvenile) leaves go into the winter season with buds at all stages of growth, and many are incompletely protected by bud scales. Inoculations made on September 11, 1914, with sporidia succeeded on the primary leaves, on the secondary (mature) leaves, and on the epidermis of growing buds and of young shoots. Yellow spots were present on all these parts in the spring of 1915.

Clinton and Miss McCormick (12, 14, 15) have recently announced successful inoculations in the leaves of *Pinus strobus*. Studies of thousands of infections show that infection takes place through the stomata of the pine leaves of all ages. Inside the stoma a sub-stomatal vesicle is formed which is of a characteristic shape. Thence the mycelium extends into the vascular bundle and then grows rapidly downward to the twig. Infection may take place in 48 hours. Inoculations on stems did not succeed. Inoculations on opened and unopened buds succeeded in a few cases, results being somewhat doubtful with the unopened ones. Infections on the leaves become visible, about a month after inoculation, as tiny yellowish spots centering on the line of stomata on the under side of the leaf. These spots turn golden yellow. Similar yellow spots may form on the twig after the fungus has become established there. A yellow mottling of the infected leaves is the principal symptom of the disease at this time.

This is rarely noted in nature, but two instances having been seen by the writer before 1920 (131, 132, 133, 134). The spots were on both leaves and stems of naturally infected *Pinus strobus* trees. Richards has recently found them on naturally infected leaves. So far as known they have been mentioned previously only by Tubeuf (174); Klebahn (71), who noted them on artificially infected trees but failed to designate the point of infection; and by Pechon (105), who observed them on naturally infected trees. The writer thought the yellow spots resulted from the growth of the fungus outward from the stem into the leaves. Klebahn seems to have been of the same opinion. It is believed that this happens sometimes. In 1920 such spots were seen on pine leaves naturally infected at Temple, N. H., and at New Boston, Mass. They are abundant in certain localities. Artificial infections have resulted from inoculations into the bark of the stem by the writer (133).

Cronartium ribicola is able to grow in bark much more than 3 or 4 years old if it once gains access to the interior. Infections have been seen which were still producing æcia on bark up to 35 years of age. A common method of infection of pine trunks 20 or more years of age is by growth of the mycelium from infected small side branches (135). (Pl. II, figs. 1 and 3.) Very often a twig near the base of a large branch becomes infected. The disease then extends

downward into the large branch, and from that into the main trunk of a tree, finally girdling it and killing the entire tree. This is true of nearly all of the older trees that have been killed in North America.

TYPES OF INFECTION ON PINES.

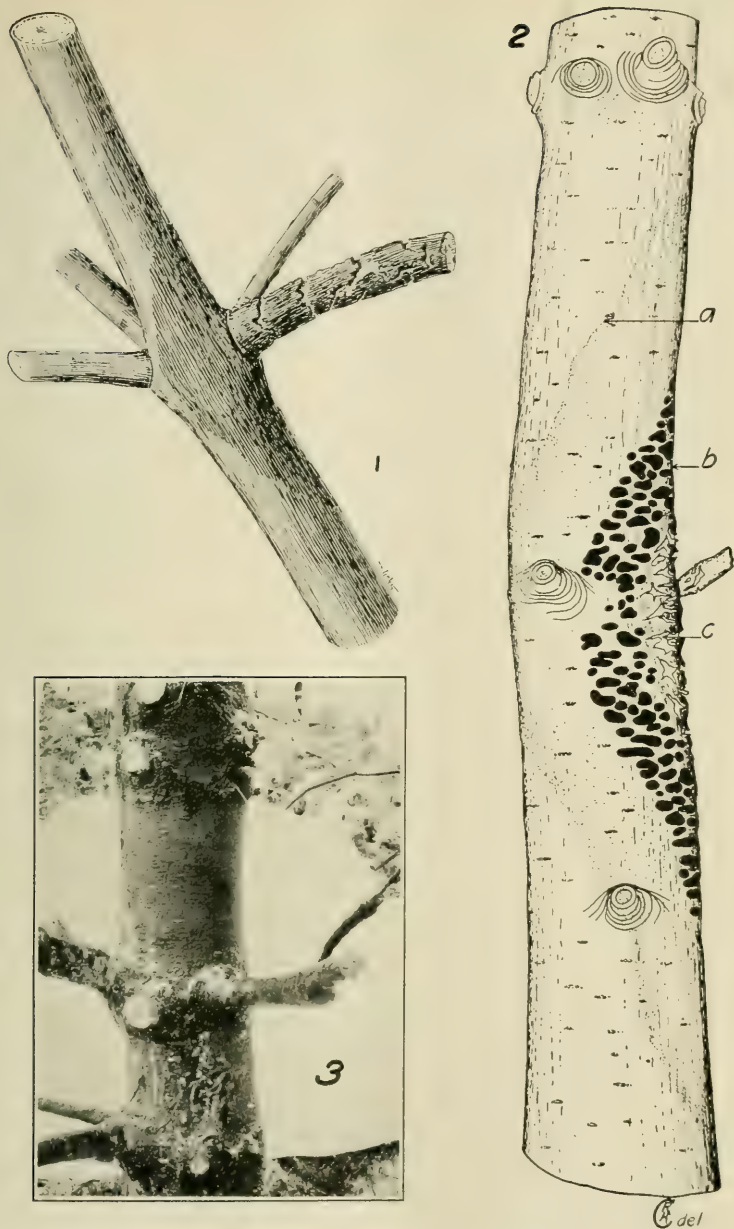
There may be said to be three types of infection on white pines resulting from natural inoculations. These are (1) direct infection of the main trunk on the leader; (2) direct infection of young branches or twigs; and (3) infection of an old trunk by spread of the mycelium from an infected branch. (Pl. II, figs. 1 and 3.) All of these are present in outbreak areas in North America. Direct infection apparently occurs only on growth not more than 3 years old. Infection of large branches or trunks, so far as we can judge, is limited only by the thickness of the bark. Old rough heavy bark of *Pinus strobus* was supposed to be immune to attack, but it has become infected by spread of the mycelium from infected side branches. It is a common method of entry of the fungus into older parts of a tree which were formerly supposed to be too old to become infected. It is very frequent in older outbreaks. This has not been mentioned in European literature until 1918 when Fischer (41) called attention to it.

DIAGNOSIS OF BLISTER RUST IN PINE BARK BY MEANS OF THE MYCELIUM.

In 1916, and to some extent before that date, when numerous specimens of diseased white pines were sent to the Office of Investigations in Forest Pathology for quick and reliable diagnosis of the blister rust, many specimens were received which bore no fruiting bodies of the parasite. The appearance of many of these made it practically certain that they were infected with *Cronartium ribicola*. Colley (16, 19) studied the problem and shortly decided that the mycelium and the haustoria did furnish reliable evidence for identifying this parasite in the bark of *Pinus strobus*. The large intercellular hyphæ, the large and abundant haustoria, and their manner of attacking the living cells, were found to be entirely different from the characters of any other known parasite of *Pinus strobus*. The use of these characters for four successive seasons with great numbers of specimens in various stages of development has indicated that such diagnosis of the disease is absolutely reliable.

LONGEVITY OF THE MYCELIUM IN PINE SLASH.

In November and December, 1916, some diseased native white pines were cut in outbreak areas in Ontario and in Maine, the slash being left lying upon the ground. Entirely independent observations made by McCubbin in Ontario and by Posey in Maine early in May, 1917, showed that new æcia were forming abundantly upon



SECTIONS OF PINE TREES, SHOWING TYPICAL PROGRESS OF BLISTER-RUST INFECTION.

FIG. 1.—Section of the trunk of a young tree of *Pinus strobus*, showing entrance of the blister rust into the trunk from an earlier infected branch. The dark shading on the trunk indicates the visibly infected portion. $\times 1$. Drawn by J. M. Shull. FIG. 2.—Trunk of young tree of *Pinus strobus*, about 2 inches in diameter, showing (by zonation) the progress of the blister rust. The disease entered the trunk from the side branch. The cracked bark (c) indicates where aecia have formed; the black spots (b) indicate the developing pycnia; the shaded part outside (a) indicates the area where the bark is discolored. $\times \frac{1}{2}$. Drawn by R. H. Colley. FIG. 3.—A trunk 8 to 10 inches in diameter. The disease attacked the swollen twig first, then ran downward to the main branch, from which it has spread into the trunk. The latter will soon be girdled and the tree will die. Photographed by J. F. Collins.

the cankers on this slash (89). This overwintering of the fungus by means of the mycelium is favored by the slash lying in moist places. It was also noted that a piece of a trunk several inches in diameter was producing new æcia after being kept in the dry air of the artificially heated laboratory in Washington about 6 weeks. These findings are significant, since they show that the cutting of diseased pines, if done in the late fall, winter, or early spring, must be accompanied by careful collection and burning of the infected slash, if infection of near-by *Ribes* is to be prevented. This difficulty may be obviated by cutting the pines in summer when the following hot, dry weather will kill the slash and end the life of the mycelium within it.

SEQUENCE OF PYCNIA AND ÆCIA AND PROGRESS OF THE DISEASE IN PINE BARK.

Study of many blister-rust cankers of varying ages in the bark of large trunks of pine has shown that the disease extends through the bark in a regular and well-defined manner. Cankers of several years' standing usually consist of four distinct zones (20) (Pl. II, fig. 2):

(1) An inner central zone of dead rough bark where æcia have been borne in preceding seasons. This area often has at its center a dead lateral branch or twig down which the disease has traveled from its first place of infection. This is the most common method by which infection of large trunks and branches takes place.

(2) An annual zone of living, swollen bark surrounding the dead area. Here is produced the latest crop of æcia. This zone varies in width from a fraction of an inch up to several inches.

(3) A zone of discolored living bark bearing the pycnial spots, drops, or scars.

(4) An outer zone of living bark, little or not at all swollen, showing a yellowing or bronzing of the normal green color of the smooth living white-pine bark. These zones of course move steadily outward with the progress of the mycelium.

This sequence of zones of activity shows that we have a regular succession of events, as follows:

(1) Invasion of healthy bark by the fungous mycelium, resulting in yellowing and bronzing of the invaded bark.

(2) Formation of pycnia in discolored and often swollen, but still living bark.

(3) Formation of æcia in living bark which has previously borne pycnia.

(4) Death of the bark which has borne æcia in abundance.

Investigations by Gravatt and Posey, and Colley (20, p. 650-651) indicate that the bark is often killed by invading secondary fungi as well as by *Cronartium ribicola* itself. Rhoads,⁷ York,⁸ and Pennington⁹ found that occasional patches of bark, where æcia have been borne the previous year, remain alive and bear a second crop of æcia the second season.

⁷ Rhoads, A. S. Studies on the rate of growth and behavior of the blister rust on white pine in 1918. Seen in manuscript. Published in *Phytopathology*, v. 10, p. 513-527. 1920.

⁸ York, H. H. Op. cit.

⁹ Pennington, L. H. Investigations on the white-pine blister rust in New York. Seen in manuscript. To be published as Tech. Bul., N. Y. State Col. Forestry.

Rhoads¹⁰ came to the conclusion that the disease spreads from the original point of infection upward and downward at about equal rates of progress. Posey and Gravatt, and Rhoads found that it spreads at nearly the same rate laterally on both sides. Progress upward and downward is usually more rapid than it is sidewise. It also appeared that in infections not yet bearing æcia, the point of greatest swelling is where infection first took place and where æcia will be first produced. Very often a dead twig or a leaf scar shows very plainly the original point of entrance of the fungus to the bark. Rhoads concluded that infections on shaded lower branches do not spread as rapidly as those on vigorously growing ones, but Posey and Gravatt¹¹ find that the former are more likely to be attacked by secondary fungi, which soon kill the branches.

Posey and Gravatt¹¹ found that there are more or less frequent instances in old infected areas of white pines where the infections on lateral branches die out. The statement (131, p. 16; 141, p. 5) that trees once infected with this fungus never recover was largely based upon studies of trunk infections. Like all rules, it has its exceptions, as here indicated. At Kittery Point, Me., Posey and Gravatt studied one of the oldest outbreaks in North America. Trees of all ages from a few years up to 50 or 75 were infected. Here it was found that secondary fungi often kill the blister rust in an infected branch and that increasing suppression of lower branches killed many of the infected ones before the blister rust spread to the trunk of the tree. It was found that about 15 per cent of all the infected trees in the area studied recovered from the disease by the action of these two factors.

THE PYCNIA AND PYCNOSPORES OF *CRONARTIUM RIBICOLA*.

The pycnospores of the Uredinales have received comparatively little attention, since it has been generally accepted that they are apparently functionless (10, 21, 70, 110, 122, 155). The writer can find but little data upon which this idea is based. Plowright (110), Thaxter (158), Jaczewski (47), and Klebahn (68) are the only investigators known to the writer who have actually inoculated plants with the pycnospores of their rusts. It seems that the pycnospores should be more thoroughly tested.

The work with pycnospores of *Cronartium ribicola* in Europe seems to be limited to that of Klebahn (68), who made inoculations with them upon young *Pinus strobus* trees without infection occurring. Even in this case there was not a clear-cut result, such as is to be desired. More recently Colley (18) has shown the importance of the pycnial spots, drops, and scars as symptoms of the blister rust in pine bark, and still more recently (20) he has investigated their morphology and cytology.

¹⁰ Rhoads, A. S. Op. cit.

¹¹ Posey, G. B., and Gravatt, G. F. Field studies on the white-pine blister rust at Kittery Point, Me. Seen in manuscript.

GERMINATION OF THE PYCNOSPORES.

Plowright states that pycnospores (spermatia) of some of the Uredinales have been germinated in sugar solutions by Cornu and himself (110). Brefeld (7) states that the spermatia of several rusts have been germinated in culture solutions. Later Carleton (10) stated that he had been able to germinate the pycnospores (spermatia) in but a single instance.

The spermatia of *Uredo caecoma-nitens* Schwein., budded sparingly on May 31, 1893, after 24 hours in a dilute solution of honey, but would not germinate in water.

Still later he said (11):

Until recent years it was not supposed that the spermatia produced regular germ tubes, but that the germination is always simply a process of budding. Dr. N. A. Cobb and the writer have shown, however, that ordinary germ tubes are produced in the germination of these spores as well as in the other spore forms * * *. Spermatia, though germinating readily in water, will be found to do much better in a rather dilute sugar solution, or perhaps still better in a solution of honey.

Investigations were made in 1918 by York and Overholts,¹² who tested their germination in water and in various solutions of glucose, cane sugar, dextrose, maltose, lactose, peptone, extract of macerated Ribes leaves, and extract of macerated pine bark. Fresh pycnospores gave no germination. Pycnospores subjected to the cold of an ordinary refrigerator from 3 to 20 days gave degrees of germination increasing with the length of time in cold up to 18 days. Germination occurred in 3, 5, and 6 per cent cane sugar and in 3, 6, and 10 per cent dextrose. The stronger dextrose solutions gave the best results. No germination occurred in tap water in any case.

SEASON OF PRODUCTION OF PYCNIAL SPOTS, DROPS, AND SCARS.

The dark spots (Pl. II, fig. 2, *b*) which precede the exudation of the pycnial drops may be found in the infected bark at all times of the year. Records and observations made from 1909 to date furnish definite data on the season of pycnial drop formation. (See Table V, p. 72.) The pycnial drops are produced immediately after the æcial season; that is, from about June 20 until winter. The rusty-brown scars left after the disappearance of the drops may be seen at all times of the year on old cankers. On new infections the scars, of course, do not appear until the drops have formed and disappeared. All of these are positive symptoms of this disease in white pines.

THE ÆCIA AND ÆCIOSPORES OF CRONARTIUM RIBICOLA.

SEASON OF PRODUCTION OF THE ÆCIA.

The æcia develop at varying dates in the same locality in different years, according to the season. The locality, whether a warm or cold exposure, at a low elevation or a high one, well to the south or

¹² York, H. H., and Overholts, L. O. The germination of the pycnospores of *Cronartium ribicola*. Seen in manuscript. To be published in *Phytopathology*.

far north, has much to do with the time that the æcia appear. They begin to push through the bark several weeks before they break open and distribute the æciospores. Open blisters have been noted as early as April 5 in eastern Massachusetts, but they were nearly three weeks later in the Adirondacks the same spring. Table V (p. 72) gives specific data so far as they are available for this and related dates.

Klebahn (68) stated that æciospores are produced by an æcium of *Cronartium ribicola* for more than 14 days. Posey and Gravatt¹³ found that æciospore production took place at Kittery Point, Me., in 1917, from April 29 to July 1.

In the spring of 1918, Rhoads made observations at Kittery Point, Me., to determine how long individual æcia produce spores.¹⁴ On May 3, he stuck pins, bearing numbered pieces of paper, into 300 æcia on various trees just as they first broke open. On May 20, the peridia of all but 63 of the æcia were entirely gone with most of the spores. On May 29 remnants of but 19 were left and on June 4, none. Therefore, in 1918 the æciospore season was about 4 weeks long at Kittery Point, Me.

York¹⁵ working at North Conway, N. H., in 1918, found that a few individual æcia contain viable spores for from 20 to about 30 days. A study of æcial production on single cankers showed that æcia matured for a period of about 30 days. These infections were all on relatively small twigs and branches. On larger branches or trunks the period may be longer. Study of the period of æcial production in that entire region showed that it was approximately 70 days. At Lewis, N. Y.,¹⁶ the æcial season in 1919 was slightly more than two months in length. After the main æcial season, late straggling æcia form. Rhoads¹⁴ noted that æcia occasionally develop on areas of bark which bore æcia the preceding year, but which were still alive.

York noted a newly formed æcium of *Cronartium ribicola* near Littleton, N. H., on July 21, 1918 (179). Several still more remarkable cases were noted by York and Ninman at Amery, Wis., on September 15 and 16, 1919. Such late æcia appear to be unknown for any of the other stem Peridermiums except *C. occidentale*, which has an æcial season from June to August. Numerous instances are known where *C. ribicola* was entirely absent on *Ribes* in a given locality early in the season, but later was found to be present in greater or less abundance. Some of these infections may originate from such late æcia. These late æciospores may remain viable over winter in the æcia, since Dosdall (29) has found that æciospores occasionally retain viability until the next spring.

¹³ Posey, G. B., and Gravatt, G. F. Op. cit.

¹⁴ Rhoads, A. S. Op. cit.

¹⁵ York, H. H. Op. cit.

¹⁶ Pennington, L. H. Op. cit.

Observations by Pennington¹⁷ on the æcia showed that more æcia were produced per canker and many new cankers were fruiting in 1919, so that more æciospores were produced that year than in 1918 in the Adirondacks. Observations on the first generation of uredinia and the results of spore-trap work indicated, however, that not as many æciospores were set free in 1919 as in 1918. This is supposed to have been due to heavy rains, which beat them down from the air. The distribution of the first generation of uredinia showed that the æciospores were as widely disseminated in 1919 as in 1918.

DISTANCE OF DISSEMINATION OF THE ÆCIOSPORES.

As is true of many of the more difficult points in the life history of *Cronartium ribicola*, European statements concerning the distance that the æciospores are distributed are based apparently mostly on personal opinions. The value to be attached to these statements seems to rest on the known excellence, or the reverse, of the published work and judgment of the writer who is being considered. European mycologists have mentioned a number of instances where this fungus appeared on *Ribes* which were said to be far removed from white pines. But some of these cases were later found to be actually much nearer diseased white pines than was at first supposed. Tubeuf (166) has stated that the æciospores spread the disease up to 500 meters or more. On the other hand, a considerable number of definite recommendations for separation of the alternate hosts set a distance of only 30 to 100 meters (131, p. 41-42).

In North America earlier field experience indicated that the æciospores spread the disease for rather short distances from their source. It was recognized from the beginning that these spores are exceedingly light and well adapted to wind dispersal, and it was stated that our knowledge of their dispersal was very limited. Special efforts have been made for three seasons to gather more data on this problem.

Posey, in 1917, set bushes of *Ribes nigrum* in a salt marsh at Kittery Point, Me., at varying distances from infected pines before uredinia were formed. Some infection resulted from æciospores upon *Ribes* plants more than a quarter of a mile from any white-pine trees. The infecting spores probably traversed several hundred yards additional, as the nearest pines were not known to be diseased. The heavily infected area was about $1\frac{1}{4}$ miles distant, and the infecting spores may easily have come that distance.

Posey also examined the islands of the Isles of Shoals, off Portsmouth, N. H., for the presence of *Cronartium ribicola*. He found no pines, but a number of *Ribes hirtellum* plants. A few leaves were

¹⁷ Pennington, L. H. Op. cit.

found infected with the fungus. In 1920, Snell reexamined these islands much more carefully. He again found the fungus on several leaves and decided that it is evidently a case where the æciospores were blown from infected pines to the islands. The islands are about 7 miles from the mainland, so that it appears that the æciospores may be blown this distance and infect *Ribes*. There appeared to be no reason for thinking the fungus wintered over. At any rate, it must have come from the mainland originally. The islands where the disease was found are very seldom visited, so carriage of spores in this way appears to be eliminated.

McCubbin (88) found that the æciospores fall about 8 feet in seven minutes in still air. This indicates a very wide potential distribution of these spores by a moderate breeze.

In 1918, York and Overholts (cited in Spaulding, 145) worked in the White Mountains of New Hampshire in a generally infected region. Much work was done with spore traps and much time spent in examination of *Ribes* plants which were isolated from white pines. The work proved that the æciospores are distributed for miles to the tops of adjacent mountains approximately 3,000 feet high, that they arrive in a viable condition, and that they are the means by which the disease spreads far and wide to *Ribes*.

In 1918, also, Pennington and Snell (cited in Spaulding, 145) worked in the eastern Adirondack region of New York. Spore traps here gave valuable contributory evidence, but study of the distribution of the first generation of urediniospores with reference to neighboring white pines gave the best results. Here it was found that spore traps caught æciospores up to 550 feet from any pines. Within a large area of cultivated land at Essex, N. Y., an intensive study was made by Snell (128) of the first generation of urediniospores. In this area the *Ribes* were found to have first-generation uredinia sparingly and widely scattered; that is, the æciospores causing the infection evidently came from a considerable distance. In one case diseased *Ribes* were found three-fourths of a mile from any white pine. Several others were found at smaller distances from any pine trees. It was concluded that the æciospores came from a distance of not less than three-fourths of a mile and probably much farther.

These conclusions concerning the wide spread of æciospores in the two localities were arrived at independently and without the knowledge by either party of what conclusions had been reached by the other.

In 1919, Snell (128) found near Rush Lake, Minn., infections on *Ribes* leaves which were $1\frac{1}{4}$ miles from the nearest pine and about 3 miles from the nearest known diseased pine. Many such infections were found in the same general area which were half a mile or more from any pine. These infections were found developing when the first generation of uredinia appeared throughout that general in-

fected area. They must have been produced by æciospores which had been blown at least the above distances.

In 1919, York caught and germinated æciospores on the summits of two mountains nearly 4,300 feet above the adjoining lowlands. It is evident that altitudes such as this do not prevent the spread of this fungus. Pennington¹⁸ caught æciospores up to 1,200 feet distant from pines and found diseased *Ribes* three-fourths of a mile from any pine tree.

AGENTS DISSEMINATING THE ÆCIOSPORES.

It has been evident from the beginning that wind is a most efficient and active agent in the distribution of the spores of *Cronartium ribicola*. While the probability of spore carriage by other agents such as insects and the larger animals was recognized, no time could be spared for work upon it. More recently, Gravatt and Marshall (45) and Gravatt and Posey (46) have made some studies of this sort.

Gravatt and Marshall worked in the experimental greenhouse where no æcia were present. They found that pycnia and the surrounding bark tissues were eaten by sow bugs.

Gravatt and Posey (46) made studies in the field in a heavily infected pine area at Kittery Point, Me. Here it was found that gipsy-moth larvæ, which were abundant, fed eagerly on the pycnia and æcia of the blister rust and also ate the bark tissues immediately adjacent to them. It was found that in some cankers a considerable percentage of the fruiting æcia were thus destroyed. But a few ingested spores remained viable, as tests in hanging drop cells in tap water yielded a few germinations. These larvæ also were carriers of abundant æciospores on their bodies, many being of a decided yellow color from the spores with which they were dusted. The gipsy-moth larvæ are known to have been blown 20 miles or more. Within the gipsy-moth infested area these larvæ are then dangerous agents in the distant spread of the disease, a fact not previously appreciated.

Notes made by Gravatt show that a wood mouse caught in the outbreak area at Kittery Point, Me., carried a small number of æciospores on its body. While squirrels, other animals, and birds have not been examined, there can be no doubt that they are active carriers of the spores. It is known that the æciospores become attached readily to clothing, and there can be no doubt that persons may carry the disease, at least locally, in this manner.

In a number of outbreak areas where pine infections were just about to produce pycnia for the first time, it was noted by several observers¹⁹

¹⁸ Pennington, L. H. Op. cit.

¹⁹ Rhoads, A. S. Op. cit.

(143, 144) that squirrels ate the swollen bark from the infected parts of the branches. (Pl. III.) They undoubtedly run over fruiting cankers and pick up æciospores on their fur and feet. Porcupines may act in the same manner. Birds undoubtedly carry these spores to some extent, and as in the æcial season they begin nesting and largely remain in the same locality they, too, act only as local carriers.

Some indications have been noted where a road traverses a narrow valley, or a narrow clearing in a forest, that automobiles create drafts which carry spores to some distance along the highway. It seems entirely possible for steam trains and electric cars to do the same thing.

POSSIBLE AUTÆCISM OF THE ÆCIOSPORES.

The possible autæcism of the æciospores of *Cronartium ribicola* has been considered. As early as 1913 field observations were made with this point in view, but no evidence of the spread of the fungus directly from pine to pine was found.

The question whether æciospores of other stem-inhabiting pine Peridermiums are capable of infecting pines has received considerable attention. In 1907 Liro (82) stated that he had made 169 inoculations of *Pinus sylvestris* with æciospores of *Peridermium pini* from the same host. No infections resulted. In 1914 Haack (48) stated that he had made similar inoculations and obtained abundant infections. His experiments were performed out of doors, with no protection from natural infection and with trees which already were naturally infected; hence, his results are worthless. In 1913 Meinecke (95) made successful inoculations with æciospores of "*Peridermium harknessii*" upon *Pinus radiata* under controlled conditions. Later (96) he changed the name of the fungus to *Peridermium cerebrum* and reported that he had successfully inoculated *Pinus radiata* with æciospores from *P. radiata* and from *P. attenuata*; and *P. muricata* with æciospores of *P. cerebrum* from *P. radiata*.

In 1915 Hedgecock (51) successfully inoculated trees of *Pinus ponderosa* var. *scopulorum*, *P. contorta*, *P. sabiniana*, *P. caribaea*, *P. mariana*, *P. pinea*, and *P. halepensis* with æciospores of "*Peridermium harknessii*" from *P. contorta*. He has also successfully inoculated *P. ponderosa* and *P. virginiana* with æciospores of "*P. harknessii*" from *P. ponderosa*.

In 1918 Klebahn (73) published the results of successful inoculations made by him with æciospores of *Peridermium pini* upon young twigs of *Pinus sylvestris*, both with and without wounds, under controlled conditions. These results throw doubt on the strict heteræcism of the æciospores of all the stem-inhabiting pine Peridermiums.

The following tests have been made with the æciospores of *Cronartium ribicola*: Klebahn (68, 70) repeatedly inoculated young



TRUNK AND BRANCHES OF *PINUS STROBUS*, SHOWING BARK INFECTIONS OF
BLISTER RUST EATEN BY SQUIRRELS.

Photographed by W. H. Snell.

FIG. 1.—An infected branch which was evidently a young infection that had not yet formed aecia. FIG. 2.—Infected bark of living tree. Here may be seen the blister-bearing central area at the base of the branches in place, while the outer, surrounding, pycnial zone has been eaten away. FIG. 3.—Infected bark of living tree. The eaten parts were where pycnia were forming.



LEAVES OF RIBES INFECTED WITH *CRONARTIUM RIBICOLA*, SHOWING DIFFERENT TYPES OF ATTACK.

FIG. 1.—Lower surface of a leaf of *Ribes aureum* infected by *Cronartium ribicola*. Note the characteristic isolated infected areas, with the abundant uredinia closely crowded together. FIG. 2.—A *Ribes* bud with a single leaf which bears normal uredinia. This leaf is relatively old, being stunted in growth by adverse conditions which have held it stationary for several weeks. FIG. 3.—Lower surface of an infected leaf of *Ribes vulgare*, horticultural variety White Transparent. Note the large infected areas merging into a single one. The uredinia are not so closely crowded together as in figure 1. FIG. 4.—Lower surface of an infected leaf of *Ribes nigrum*. Note the general distribution of the telia, their grouping closely together, and their vigor of growth.

Pinus strobus trees with æciospores, but without producing infection. Hennings (53) inoculated *P. strobus* trees with æciospores and also with teliospores. No infection resulted from either. In the spring of 1916 the writer made 100 inoculations with wounds into the bark of *Pinus strobus* trees, out of doors, with fresh æciospores of *Cronartium ribicola*. No infections have resulted to date. In May, 1917, the writer (146) inoculated white pines by dipping the tips of young twigs in water containing great quantities of newly formed æciospores of *C. ribicola*. The needles as well as the twigs were covered with spores. Glassine bags, containing wet wads of cotton, were then tied over the inoculated twigs to keep up the humidity of the air. No evidence of infection is yet visible.

GERMINATION OF THE ÆCIOSPORES.

Experience shows that fresh æciospores taken from æcia just as they are about to break open, or just at the time of breaking, possess maximum infective power. Doran (28) confirms this opinion. Inoculations made with such spores are sure of results if conditions are at all favorable. Older æciospores are erratic in germination, but some of them retain viability to a marked degree. Cooling on ice stimulates their germination to a decided degree, as is shown by experiments performed by Eriksson (32), Gravatt, and others. Each spore produces from one to five (20, 29) germ tubes, which branch freely. The viability of fresh æciospores is generally high, as many as 95 per cent germinating under favorable conditions. They require 8 to 10 hours to germinate (28).

Doran (28) determined the minimum, optimum, and maximum temperatures for the æciospores of *Cronartium ribicola*. Five series of tests were made. It was found that germination in distilled-water drop cultures occurred through a range of 12° C., but the percentage of germination dropped rapidly both above and below the optimum. The minimum temperature for the æciospores was 5° C., the optimum was 12° C., and the maximum was 19° C.

LONGEVITY OF THE ÆCIOSPORES.

Klebahn (70, p. 26) seems to have been the only European investigator who has tested the longevity of æciospores. He found them strongly viable after seven weeks.

From the beginning of the work of the writer on *Cronartium ribicola* it has been known that the æciospores retain their viability for a relatively long time under favorable conditions. In 1910 a single æciospore which had been kept in the laboratory for more than five months in an open æcium on a diseased young tree which was dried and kept as a specimen germinated in water (131, p. 30). In 1915 McCubbin (85) collected on May 6 a diseased young white

pine bearing æcia. It was placed in a box in the laboratory and allowed to dry out. Tests were made by inoculating leaves of *Ribes nigrum* plants on May 7, May 21, June 4, and June 23. On the last date no infection occurred. In 1916, McCubbin repeated these experiments and found that the æciospores remained capable of infection under the conditions of his experiment at least 39 days. He believes they may retain viability considerably longer, as his tests were conducted under adverse conditions.

Æciospores collected on April 9, 1917, and kept in a closed glass vial were tested by Gravatt weekly in hanging drops of distilled water. They gave good germination for about one month, then weakened until June 9, when the last germination occurred. The tests continued until July 14. On May 7, 1917, another series of similar tests was started by Gravatt and Taylor. (See Table II.) The æciospores were placed in two glass vials with cheesecloth tied over the tops. One vial (B) was kept out of doors on a window sill on the north side of a building where the sun did not shine. The other vial (A) was kept in a dark refrigerator. The spores were tested weekly in distilled water. In most cases the cultures were placed in an ice box for about 12 hours. The spores kept in the ice box retained their color throughout, while those on the window sill had faded perceptibly by June 16. Lot A varied in germination from 8 per cent at first to 3 per cent on June 2. Germination persisted until July 2, when the last occurred in this lot. Lot B germinated freely until May 26 and not at all after June 23. Cooling and darkness in this case decidedly stimulated germination for one month and prolonged viability about 10 days after the uncooled æciospores which were exposed to light had lost all viability.

TABLE II.—Longevity of the spores of *Cronartium ribicola*.

Date, 1917.		Germination (per cent).						Notes.
		Lot A, vial in refrigerator.			Lot B, vial out of doors.			
		Æcio- spores.	Uredi- nio- spores.	Telio- spores.	Æcio- spores.	Uredi- nio- spores.	Telio- spores.	
May 8.	8	13	90	8	8	85	Not cooled in refrigerator before germination. Do. Lot A somewhat faded. Lot A much faded. Teliospores in lot A mouldy. Æciospores and urediniospores mouldy in lot A, color of lot B still fairly good.	
May 12.	8	10	85	1	10	90		
May 19.	5	60	80	2	40	85		
May 26.	4	45	70	3	37	50		
June 2.	3	6	40	.8	.8	10		
June 9.	1	.65	51.3	.1	1.5	4.4		
June 16.	.1	1.35	4.5	0	0	0		
June 23.	0	0	3.5	.05	0	0		
July 2.	.05	0	.5	0	.1	-----		
July 7.	0	0	0	0	0	-----		
July 14.	0	0	0	0	0	-----		

In April, 1918, Dosdall tested in distilled water (in hanging-drop cultures) the viability of æciospores produced in 1917 (29). On April 19, 1918, a dead white-pine branch bearing a canker which had fruited in 1917 was collected at Rush Lake, Minn. While new æcia were just beginning to break open on other cankers at this time, the spores tested were not new ones, as they were dug from the bottoms of 1917 cavities after scraping off the outer exposed spores. Nor could there have been new æcia pushing up beneath the old ones, as the branch was dead. It was found that from 1 to 2 per cent of the spores germinated in distilled water, each spore producing from 3 to 5 germ tubes. It is barely possible that these spores were from an abnormally late æcium (179) and therefore were not so old as Dosdall supposed them to be. Even so, they must have been approximately 6 months old.

This experiment of Dosdall has been repeated. A dead branch bearing æcia of 1918 was collected at Kittery Point, Me., on February 25, 1919, and taken to Washington, D. C. Taylor tested the æciospores by hanging-drop cultures in tap water, but no germination of the spores could be demonstrated. Spores of other fungi were present and did germinate.

York²⁰ collected a specimen of diseased white pine bearing newly formed æcia on April 30, 1918. This was put in a paper bag and left in the laboratory away from direct sunlight until October 5, 1918. He then broke open a still unbroken æcium which had not pushed through the outer bark and made cultures of the spores. He got some germination in tap water under these condition 157 days after collection of the material. The spores were still yellow when the test was made. Spores from æcia which had broken open did not germinate.

During the season of 1918, Pennington²¹ found that in the Adirondacks the æciospores remained viable for at least four weeks after being removed from the æcia and stored in a dry place. The same season, York found that in the White Mountains æciospores from blisters in cankers cut from the tree and kept in the shade out of doors remained viable for 75 days, as shown by tap-water cultures and inoculations on *Ribes* leaves.

In 1919, Pennington²¹ found that æciospores, whether brought into the laboratory or left in the field soon lost their viability, less than 1 in 400 germinating after three weeks from the breaking open of the æcium producing them. Tests upon the viability of æciospores after they had been exposed to direct sunlight showed a decrease of 50 to 75 per cent in viability after three hours' exposure. After an exposure of eight hours, some of the æciospores (1 in 1,500 or 2,000) were still viable.

²⁰ York, H. H. Op. cit.

²¹ Pennington, L. H.. Op. cit.

Doran (28), in 1919, found that the æciospores germinate well in distilled-water drop cultures for four weeks, when germination weakens. Germination ceased after six weeks. He does not give details of the conditions of storage of the spores.

Pennington ²² compared the number of æciospores caught in spore traps with the number of infections on *Ribes* leaves and estimated that under the most favorable conditions 1 spore in every 25 which lodged upon a *Ribes* leaf produced infection there. An estimate for the season showed that not more than 1 in 100 produced infection.

The Cronartium Stage on Ribes.

THE INCUBATION PERIOD ON RIBES.

The length of the incubation period between infection of *Ribes* by æciospores and urediniospores of *Cronartium ribicola* and the production of mature uredinia or telia varies greatly, according to the external conditions of temperature and moisture and the age and condition of the leaves infected. Examination of the records of 493 inoculation tests made in the greenhouse show that the shortest incubation period between infection and formation of mature uredinia is practically 7 days. These records show that 2.4 per cent of the cases fruited in 7 days, a like number in 8 days, 7.3 per cent in 9 days, 10.4 per cent in 10 days, 20.8 per cent in 11 days, and 19.7 per cent in 12 days. The percentage rapidly drops after this to 9.7 per cent in 13 days, 8.1 per cent in 14 days, 8.5 per cent in 15 days, 8.1 per cent in 16 days, and 3.2 per cent in 17 days.

Pennington ²² found that the incubation period on *Ribes* in the eastern Adirondack region with both æciospores and urediniospores was 11 to 18 days; it was usually 13 to 15 in mature leaves and somewhat longer in leaves which were very young when inoculated.

There are times when the fungus produces only uredinia in the greenhouse as well as in the fields. The behavior of the fungus is not entirely controlled by weather conditions, but is greatly influenced by the condition of the host leaves. At other times the fungus will produce nothing but telia. At such times telia are produced in a very short time after infection. Telia have been obtained in 9 or 10 days after infection. From 12 days upward they may be formed at almost any time up to 2 or 3 months after infection.

York ²³ in many cases has obtained telia directly from æciospore as well as urediniospore inoculations upon overmature ²⁴ leaves.

²² Pennington, L. H. Op. cit.

²³ York, H. H. Op. cit.

²⁴ The term "overmature" is here used to denote that stage of development of *Ribes* leaves where they have become tough, leathery in texture, and of maximum thickness, but have not begun to decline in photosynthetic activity.

METHODS OF INOCULATING RIBES.

The methods of inoculating Ribes plants are not claimed to be original with the writer or his associates. It is well known that some of these methods have been in use for many years. They are given here to show the conditions under which the experimental work was done, as follows:

(1) When plenty of spore material is available, as is usually the case with aciospores, the spores may be placed in a considerable quantity of water and the top or branch of the Ribes plant dipped into it. The spores will be distributed quite evenly over all parts of the dipped plant. (See Clinton (12).) This method was used by the writer as early as 1909, and has been very successful. It uses up large quantities of inoculum, however.

(2) Another method which has been much used is to spray water from an atomizer upon the part to be inoculated, then shake the dry spores upon the wet surface. This also requires a plentiful supply of inoculum. It has been a favorite method, as it gives good results with reasonable certainty.

(3) When inoculating with urediniospores from fresh leaves, the part to be inoculated is sprayed, and the leaf bearing the inoculum is turned with its lower surface on that of the healthy leaf and the two rubbed lightly together.

(4) If the inoculum is scanty, the spores are moistened with a drop of water and lightly scraped off upon the moistened healthy leaf with a sterilized scalpel or knife blade.

(5) If the inoculum is in moderate quantity, the spores are placed in a small quantity of water in a sterilized atomizer and sprayed upon the healthy plant.

(6) The spores, if fairly plentiful, are sometimes collected in a watch glass, a small quantity of water added, and then a clean camel's-hair brush is dipped into the mixture and brushed over the surface to be inoculated. With this method it is advisable to wet the inoculated part with an atomizer after inoculation, or results will be meager.

(7) Occasionally healthy leaves have been rubbed or dipped in the spore mixture described in paragraph 6.

Gravatt made comparative tests of some of the foregoing methods of applying the inoculum. This comparison showed one-fourth more infection with method 5 than with method 6, with three different species of Ribes. General experience has shown the order of efficiency of the methods to be as follows: 1, 5, 2, 6, 3, 7, 4. This is probably largely due to the greater number of spores used by the more successful methods. All will give good results when the relative number of spores used is considered.

With all these different methods of applying spores and moisture, it is essential to supply all the water possible without having it form large drops and run off.

As a supplement to the local moistening, it is necessary to keep the inoculated plant in a moist chamber for 12 to 24 hours. In the experiments by the writer and his associates the preferred method has been to keep the plant in the moist chamber 48 hours.

The matter of a proper moist chamber is a problem of considerable moment. Glass bell jars are good, but costly and easily broken. A tightly closed wooden and glass chamber of considerable size was

tried, but is unsatisfactory because the tender leaves of the inoculated plants are liable to scald in hot weather. Hunt (57) tested a form of the iceless refrigerator for this purpose. This is a modification of the field moist chamber described by Keitt (61, p. 540-541), without a continuous water spray. It is essentially a framework large enough to receive several potted plants, on top of which a large pan of water is placed. Around the framework is fitted a loose curtain of heavy cheesecloth completely surrounding the framework on the sides and extending from the water in the pan on top to the ground. In use, the cloth is wet thoroughly and the water in the pan keeps it wet. This keeps the air within the chamber saturated with moisture and cool, which is the desired condition for the plant. This has been very successful even in the hottest summer weather and has the desirable qualities of durability, cheapness, portability, and simplicity.

Clinton (12) has recently reported the successful inoculation of plucked leaves of *Ribes* in moist chambers. This is an old method with the rusts, and was used by Barclay in India as early as 1887 (4). Clinton has apparently developed this method to a point of maximum efficiency. It has not been used in the investigations by the writer and his associates, the preferred method being to retain natural conditions as far as possible in making susceptibility tests.

FACTORS CONTROLLING THE INFECTION OF RIBES.

Among the factors controlling infection of *Ribes* by *Cronartium ribicola* may be mentioned moisture, sunlight, age of leaves inoculated, and age of inoculum.

Frequent allusions are made by investigators to the need for abundant moisture in producing the infection of *Ribes* by æciospores and urediniospores of *Cronartium ribicola* and in spreading the fungus on *Ribes*.

In 1904, Aderhold (1) performed a series of experiments to determine the influence of moisture upon the infection of *Ribes vulgare* by æciospores of *Cronartium ribicola*. He had two inclosed cells, the air in one of which was moistened by artificial rain, while in the other it was kept relatively dry; he had similarly arranged plats open to the free air. The conditions in these cells and plats he summarized, as in Table III.

TABLE III.—Conditions in cells and plats of Aderhold's experiments.

Experiment.	Air.	Temperature.	Moisture.	Amount of light.
1. Rain cell.....	Motionless.....	High.....	Very great.....	Small.
2. Dry cell.....	do.....	Very high.....	Slight.....	Do.
3. Open rain plat.....	Moving.....	Below normal.....	Great.....	Great.
4. Open dry plat.....	do.....	Normal.....	Normal.....	Do.

Aderhold placed his experimental plants in these cells and plats on April 16. On May 6 all of the plants were heavily dusted with æciospores, and half of those in each cell and plat were put under conditions opposite to those they were in before inoculation. The plants from the closed rain cell when inoculated and replaced in the same cell took the disease heavily. Those from the closed dry cell when inoculated and placed in the closed rain cell also took the disease heavily. Those transferred from both the rain and dry cells to the dry after inoculation showed no infection. All the plants kept in the open plats failed to take the disease. It is apparent from his results that infection depends upon an atmosphere that is nearly saturated with moisture.

Experience in the greenhouse has shown that it is necessary to have abundant moisture on the leaf surface for infection to succeed. The leaf itself must be wet, without having large drops of water collect. This moisture must be retained for some time by keeping the surrounding air saturated with water vapor. Gravatt made a series of parallel tests, part of the inoculated plants being kept under bell jars 2 hours, part of them 7 hours, and another part 24 hours. Infection occurred with the 7-hour and the 24-hour plants, but not with the 2-hour tests. The writer made a series of inoculations in the greenhouse with æciospores without putting the plants in moist chambers. Not one infection resulted within 14 days, the usual time necessary to reach full fruiting condition. The plants were then put into moist chambers for 48 hours, and fair infection resulted from the spores put on the leaves 14 days before. Ewert (37) performed a similar experiment in 1912 with the same results, as did Werth (177) in 1915 and York²⁵ in 1919. McCubbin in 1916 inoculated two leaves on each of seven shoots of a *Ribes nigrum* plant. Two of the shoots were put in a moist chamber for 48 hours. The remaining five shoots were left uncovered. The leaves of only the two inclosed shoots developed infection.

It is equally necessary to have plentiful moisture for infection to occur out of doors. Hennings (53) found a severe outbreak of the disease on *Ribes* during a dry time in the Dahlem Botanical Garden, but he attributes the intensity of the attack to the daily watering (sprinkling) of the bushes. Ewert (35) says, "In the summer of 1902, moisture, the important factor for infection, was not lacking, so all conditions were favorable for the spread of the *Cronartium*." Schellenberg (123) attempted to inoculate *Ribes* bushes with æciospores from *Pinus cembra* in the open air. He attributes his failure to produce infections to the bright sunny weather prevailing at the time. In 1910, the writer (131) inoculated *Ribes* leaves with fresh

²⁵ York, H. H. Op. cit.

æciospores out of doors. The leaves were not wet, but there was dew every night. No infection resulted.

In 1913, Stewart and Rankin (151) made some observations on this problem. On May 14 two white-pine trees were found bearing abundant open æcia. On May 17, they were cut down and burned. About 120 feet from the pines there was a small plantation of *Ribes nigrum* and *R. vulgare*. The weather was dry and unfavorable for infection of the currants to take place for several days before May 15. The forenoon of May 15 was damp, but in the afternoon it dried off and remained dry until after the trees were destroyed. They concluded that the infection of *Ribes* which developed on June 10 apparently could have taken place only in the wet forenoon of May 15. It appears to the writer that the long incubation period indicates that the spores from the pines stuck to the *Ribes* leaves without germinating until a later rainy period long enough for infection to occur.

Studies made by Pennington²⁶ and Snell (145) in New York in 1918 on *Ribes rotundifolium* show the absolute dependence of the spread of this fungus upon moist weather. They found that six distinct generations of urediniospores were produced during the season, with a slight seventh one the last of the summer. These appeared approximately two weeks after spells of rainy weather. York working in the White Mountain region for three years has made a great many successful field inoculations on various species of *Ribes* without using any form of moist chamber. His work was largely carried on, however, in localities naturally moist.

Temperature also is an important factor. Probably much of the efficiency of Hunt's iceless refrigerator inoculating chamber is due to the rather low temperature obtained. *Cronartium ribicola* is favored by low temperatures, as is shown by the optimum temperatures determined for it by Doran (28). Doran also inoculated plants of *Ribes* which were then kept at 3°, 12°, and about 22° C. No infection occurred on the first and last, while the one at 12° C. developed uredinia.

Sunshine is an important factor, indirectly if not directly. Its direct influence upon the spores is destructive (30, 88) but it is doubtful if this action is powerful enough to hinder germination greatly if sufficient moisture is present. Indirectly sunshine affects infection by quickly reducing moisture. It seems that a moderately cool temperature is most favorable and that bright sunlight may elevate the temperature above the optimum for the fungus.

The size of the leaves alone seems to have little or no influence upon their susceptibility to infection (147). Leaves as small as

²⁶ Pennington, L. H. Op. cit.

4 mm. wide have been found bearing groups of uredinia (Pl. IV, fig. 2).

The age and relative maturity of the leaf has much to do with its susceptibility. It has been the general experience that *Ribes* leaves may be overmature and also may be too young to take the disease. Infection does not occur on the leaves of a given species of *Ribes* until they have reached a certain degree of maturity. Leaves produced by buds developing in late summer or fall, even if very small, readily become infected. The different species of *Ribes* vary much in this regard. *Ribes nigrum* shows a great range in its age of susceptibility, while resistant species become infected only on leaves of a certain maturity. The most favorable stage of growth seems to be about when the leaf attains full size but has not become hardened and leathery as it does later. Tests were made by Gravatt in 1915 in the greenhouse on *Ribes nigrum*. The plant had three shoots of nearly equal size and development. They bore fully mature leaves at the base and had leaves at the tips about half grown. In this case all the leaves became infected except the lower three or four on each shoot. In 1916, McCubbin (ms. report) made several series of inoculations with æciospores upon *Ribes nigrum* leaves of various ages. The plants were not kept under the best growing conditions, so the results are less pronounced than might otherwise be expected. He produced no infection on the youngest leaves. The older ones took the disease, but the overmature ones took it least of all. York²⁷ made greenhouse tests with plants of *Ribes nigrum*, *R. triste*, *R. glandulosum*, *R. hirtellum*, and *R. lacustre*. Leaves of various ages were present on all the plants. The mature ones showed infection first. The degree of infection was heaviest on the first species and decreased in the order named, *R. lacustre* having but two pustules on a single leaf. Later, the half-mature leaves of *R. nigrum* and the leaves of *R. triste* and *R. glandulosum* two-thirds mature became infected. The younger leaves did not become infected then, but when reinoculated later they took the disease, except that those of *R. lacustre* remained healthy. In most inoculation tests made by the writer and his associates in the greenhouse both the oldest and the youngest leaves remained free from disease, although they were treated exactly like the others. York²⁷ tested this point extensively in the open in 1918 and found that leaves just unfolding were almost invariably immune to the fungus; older ones took the disease readily; and overmature ones (especially late in the season) were immune. Pennington²⁸ reached similar conclusions working independently.

²⁷ York, H. H. Op. cit.

²⁸ Pennington, L. H. Op. cit.

Snell²⁹ made inoculations out of doors with spores from unopened æcia on April 30, 1918. He inoculated opening buds of *Ribes glandulosum* by carefully inserting a knife so as not to injure the leaflets and inserting the spores between the folds of the leaves. The largest leaves were 3 cm. broad, the smallest 3 to 5 mm. long. It was very rainy, so there was plenty of moisture. No infection was visible on May 15, but on May 22 heavy infection was present on all the leaves inoculated. The leaves on this date ranged from nearly full size to those just opening. The infection was heaviest on the largest leaves inoculated and decreased to a light infection on the smallest. The check plants were healthy. There are two possible factors which might have delayed the infection a week longer than usual. These are cool temperature and the immaturity of the leaves. The experience of the writer leads to the belief that the latter was the principal factor involved in this case. Later Snell found natural infection on leaves of *Ribes vulgare* that were only 12 mm. wide.

It has been noted repeatedly that the earliest infections on *Ribes* leaves in the spring are about a month later than the time when the first æciospores are set free. It is a question whether this is due to very cool nights or to the immaturity of the *Ribes* leaves at this time. Noninfection of immature leaves in the greenhouse leads the writer to suspect that the latter is the main factor involved. European writers (63, 101) have stated that *Cronartium ribicola* is decidedly earlier than the native pine-stem *Peridermiums*.

Observations made by Gravatt at Block Island show that new infection in midsummer was present upon the fifth to the eighth leaves from the tip, not counting those less than 5 mm. wide; that is, on leaves just mature but not hardened.

Gravatt and York and Overholts made many inoculations of leaves, petioles, and stems with wounds, but found no evidence that infection was favored by wounds.

Whether viability of spores of *Cronartium ribicola* in culture solutions, water, etc., is a reliable index of their infective power (43) is a question which has arisen more or less insistently since inoculation experiments began. Klebahn (70) made a definite test with reference to this question with æciospores of *Cronartium ribicola*. The spores were collected on March 20 and kept dry until May 8 when the test was made. Some were sown on the leaves of *Ribes aureum*, some were sown on a cover glass coated with a thin layer of sterile *Ribes*-decoction agar, and others were sown on a cover glass moistened with water. The cover glasses were kept in a moist chamber to prevent drying. The *Ribes* plants became infected after 12 days on every leaf inoculated. The spores on *Ribes*-decoction agar germinated

²⁹ Snell, W. H. Period of exposure and size of *Ribes* leaves infected by the blister-rust fungus. Seen in manuscript. To be published in *Phytopathology*.

slowly at first, but later developed strong germ tubes in considerable quantity. Scarcely a spore in water germinated. As a result of his extensive experience with the rusts, Klebahn says:

. . . in other words, I believe it possible for spores which do not germinate in water to infect leaves of the host plant, and it seems to me to be expedient to distinguish between "infection power" and "viability" of spores more sharply than is ordinarily done.

Gravatt had experiences somewhat similar to the above in his inoculations with urediniospores of *Cronartium ribicola* in 1917. So pronounced has been our general experience in this regard, that many germination and longevity culture tests made in 1918 and 1919 were duplicated by check inoculations on favorable hosts so far as possible.

LOCATION OF THE INFECTIONS ON RIBES PLANTS.

SORI ON THE LEAVES.

The usual place for uredinia and telia of *Cronartium ribicola* to form is on the lower side of the Ribes leaf blade. It is rather exceptional for them to appear elsewhere. Nevertheless, they are occasionally found on the upper side of the leaf blade. They have been noted there by Gravatt in the greenhouse and by several out-of-door workers on Block Island. The following species have been seen with uredinia or telia on the upper leaf surface: *Ribes alpestre*, *R. aureum*, *R. cereum*, *R. fasciculatum*, *R. fontenayense*, *R. hirtellum*, *R. odoratum*, and also the horticultural varieties *R. aureum* var. Utah Yellow and *R. vulgare* var. White Imperial. It must not be concluded that because fruiting bodies are found on the upper surface of leaves that the infection took place there. On the contrary, in every case seen, it was very evident that the fungus had attacked the infected leaf beneath, and the attack had been so intensive that some sori were pushed through to the upper surface. There never were as many sori on the upper surface as there were on the lower one, nor were they so old.

Some inoculations have been made in Europe to determine if infection may take place on the upper surface of Ribes leaves. So far as known to the writer they are here summarized:

In 1913 Ewert (37) brought four potted plants of *Ribes nigrum* into the greenhouse. On April 10 he inoculated the leaves of one branch of plant 1 on the lower surface only with fresh aeciospores. The plant was inclosed in a glass cylinder as a moist chamber. Another branch was used as a check. On April 28 the inoculated branch bore uredinia upon 11 leaves. On April 15 he inoculated the leaves of a third branch, but did not inclose it in a moist chamber. On April 26 there was no sign of infection, and it was then inclosed in a moist chamber. On May 20 all the inoculated leaves bore uredinia. The control remained healthy.

Plant 2 was treated exactly like plant 1 except that the inoculations were made on the upper sides of the leaves. No infection resulted.

Plant 3, on April 10 and 15, was inoculated on one branch on only the lower surfaces of the leaves. Another branch was inoculated on the upper surfaces only. A third branch was left as a check. Weak infection resulted on the first branch. A repetition on April 29 with fresh æciospores gave better results.

Plant 4, left untreated, was in another inclosure of the greenhouse. It remained healthy, showing that infection had not occurred before the plants were brought into the house.

On May 26 similar inoculations were made by Ewert with uredinio-spores on the upper sides and lower sides of leaves. Infection resulted in the latter case and also a slight infection of the lower surface of one leaf which was inoculated on the upper surface.

Another similar series of inoculations made by Ewert on June 6 gave infection only on the leaves inoculated on the lower side. He fails to say in all cases that the sori formed only on the lower surface of the leaves, but his language implies that this is the case. Attacking the problem in another way, Ewert (37) sprayed *Ribes nigrum*, *R. aureum*, and *R. rubrum*, leaves, part on the lower side only, part on the upper side only, and part on both sides, while controls were left unsprayed. The details are presented on pages 77 to 79. Because some leaves which were sprayed on the upper side developed a few sori beneath, he appears to be a little doubtful whether infection may occur on the upper surface, but he concludes that it "apparently almost exclusively takes place on the lower surface of the leaf."

The writer and his associates have made hundreds of inoculations on the upper surface of leaves of many species and varieties of *Ribes*, without a single direct infection occurring there. Numerous instances have been noted in these experiments in which infection appeared on the lower surfaces of leaves that had been inoculated on the upper side. This is believed to be due to spores reaching the lower surface in some unknown way. In fact it is very difficult if not impossible to guard against this. York and Overholts inoculated leaves of *Ribes glandulosum* on the upper side, both with and without ring cells, to prevent the spores reaching the lower surface. Slight infection occurred on the lower side in some cases where cells were not used. Where the cells were used no infection occurred. These tests were made on leaves of different ages on plants of various ages, from young seedlings up to fruiting bushes. Tubeuf (173) inoculated leaves of *Ribes nigrum* on the upper side by applying the spores in water with a brush. All of the leaves thus inoculated remained healthy except a single one which had a uredinium on the lower surface. He was uncertain whether a spore infected it through the lower surface or through a lesion on the upper surface.

SORI ON COTYLEDONS.

The cotyledons of young *Ribes* seedlings are apparently quite susceptible to infection by æciospores and urediniospores of *Cronartium ribicola*. Relatively heavy infection has resulted from inoculations on the lower surface of cotyledons of *Ribes americanum*, *R. missouriense*, *R. oxycanthoides*, *R. rotundifolium*, *R. glandulosum*, and *R. fasciculatum* seedlings in the greenhouse and on *R. glandulosum* in the field.

SORI ON FLORAL BRACTS AND BUD SCALES.

Infection was secured by Gravatt from inoculations of the floral bracts of *Ribes aureum* in several different cases in the greenhouse.

Infection of opening buds and of bud scales merits more investigation. McCubbin (85) suggested the possibility of infection of partially open buds in the fall and the overwintering of the fungus, but he could not prove that it occurs. Infection of young leaves scarcely out of the bud occurs, but it seems to be limited to leaves that are relatively mature, though small. (See discussion on pp. 44 to 46.) Search for infections of buds on heavily infected *Ribes nigrum* bushes failed to reveal any infections (151, p. 44). Gravatt made inoculations of buds about to open, but with no success. York³⁰ has inoculated successfully an inner bud scale of *Ribes nigrum*.

SORI ON PETIOLES.

Next in frequency to infection of the lower surface of the leaf blade is infection of petioles. The first published account of this, so far as the writer knows, was given in 1912 (133, 134, 135) and 1913. At that time it was considered to be very uncommon. Since then a considerable number of such cases have been noted both in the greenhouse and out of doors. The following species have developed uredinia or telia, or both, upon petioles, as many as 25 or more petioles on a single plant being thus attacked: *Ribes americanum*, *R. aureum*, *R. bracteosum*, *R. cereum*, *R. culverwellii*, *R. cynosbati*, *R. divaricatum*, *R. erythrocarpum*, *R. fasciculatum*, *R. giraldii*, *R. glandulosum*, *R. inerme*, *R. lacustre*, *R. nevadense*, *R. nigrum*, *R. parishii*, *R. petraeum*, *R. robustum*, *R. setosum*. The following cultivated varieties have had petiolar attacks: *Ribes nigrum* hort. vars. Black Victoria, Climax, and Seabrook Black; *R. reclinatum* hort. vars. Berkeley, Golden Prolific, Poorman, Transparent, and Van Fleet; *R. vulgare* hort. var. White Imperial. Some 10 or 12 as yet unidentified species collected by Beattie in the Rocky Mountain and Pacific coast regions have exhibited the same phenomenon.

³⁰ York, H. H. Op. cit.

In many cases the petiole became diseased by growth of the mycelium downward from the leaf blade into it, but direct infection of the petiole occurs occasionally. This is shown by the presence of infections on the petiole one-half inch or more distant from other infections. Microscopic examination by Colley in such instances has shown the intervening tissues to be entirely free from migrating mycelium. York³¹ had several instances where infection took place well down on the petiole, and no other infection was present either on that petiole or the leaf blade. While many inoculations of petioles have been made by members of the Office of Investigations in Forest Pathology, but few have been successful, as above indicated.

SORI ON STEMS.

Evidence of infection of *Ribes* stems has long been sought. In 1917, Posey, Gravatt, and Colley (112) discovered three uredinia on young stems of *Ribes hirtellum* which resulted from natural infection in an outbreak area. Artificial inoculations on young stems of the same species with æciospores produced 18 more uredinia. A single stem infection was produced by Gravatt in the greenhouse upon a young seedling of *R. fasciculatum* (Pl. V, fig. 2). Æciospores were used in this case also. While the tender stem was completely girdled, it survived long enough to form wood and finally completely outgrew the disease. Since then Taylor has successfully inoculated with æciospores the stems of young seedlings of *Ribes missouriense* and of *R. americanum* in the greenhouse. York has infected stems of young *R. glandulosum* plants with æciospores and urediniospores out of doors, and has found natural infections on the same species and on *R. cynosbati*. He has infected a young stem of a 2-year-old plant of *R. cynosbati* with æciospores in the greenhouse.

RELATION OF STOMATA TO THE INFECTION OF RIBES.

A number of investigators of the Uredinales have stated that æciospore and urediniospore germ tubes obtain entrance to their hosts through the stomata (34, 70, 110, 149, 171).

As heretofore stated, *Cronartium ribicola* infects the *Ribes* plant on the lower side of the leaf mostly. Less frequently it infects the petioles, floral bracts, and cotyledons. It may infect young stems. Infection never occurs on the upper surface of the leaf. Examination of a number of different species of *Ribes* has been made by members of the Office of Investigations in Forest Pathology. Data on the stomata may be summed up as follows:

Stomata were present in large numbers on the lower surface of leaves of all species examined. Stomata were present in small numbers on the upper surface of leaves of *Ribes cereum* (60, 78), *R. inebrians* (60, 78), *R. odoratum* by Marshall, *R. orientale* (160), and

³¹ York, H. H. Op. cit.



LEAVES AND PLANT OF RIBES, SHOWING INFECTIONS OF CRONARTIUM RIBICOLA.

FIG. 1.—Upper surface of a leaf of *Ribes cynosbati* infected by *Cronartium ribicola*. Early stage of dying of the leaf tissue. FIG. 2.—Seedling of *Ribes fasciculatum* with stem infected by *Cronartium ribicola* as a result of inoculation with ascospores. FIG. 3.—Upper surface of an infected leaf of *Ribes verticillatum*, horticultural variety Smith. This is quite resistant. Leaf tissue already dead. FIG. 4.—Upper surface of infected leaf of *Ribes vulgare*, horticultural variety Padua. Quite resistant. A more advanced stage in death of attacked leaf tissue. Painted by J. M. Shull.

R. vulgare by Marshall. None were found by Unger (176) on the upper surface of leaves of *R. alpinum* nor by Taylor on *R. americanum*, *R. aureum*, *R. carrierii*, *R. culverwellii*, *R. fasciculatum*, *R. nigrum*, *R. reclinatum*, *R. speciosum*, and *R. (tenuiflorum) aureum*. Stomata were found only on the lower surface of cotyledons of *R. fasciculatum* and *R. missouriense*, the only ones examined by Taylor. Stomata were found by Taylor to be not uncommon on petioles of *R. americanum*, *R. aureum*, *R. carrierii*, *R. culverwellii*, *R. hirtellum*, *R. inerme*, *R. nigrum*, *R. odoratum*, *R. reclinatum*, *R. sanguineum*, *R. speciosum*, *R. succirubrum*, *R. (tenuiflorum) aureum*, and *R. vulgare*. Nonè were found on petioles of *R. curvatum* and *R. fasciculatum*. Janczewski (60) states that stomata are present on the young stems of *R. petraeum*. A few stomata were found on young stems of *R. aureum*, *R. hirtellum*, *R. nigrum*, *R. odoratum*, *R. reclinatum*, *R. succirubrum*, *R. (tenuiflorum) aureum*, and *R. vulgare*. None were found on the stems of *R. carrierii* and *R. fasciculatum*. These findings compare well with the inoculation results, if stomata are the avenue for infection. It is perhaps to be expected that infection may be produced on the upper surface of the leaves, but only very rarely. Colley (20) found young uredinia forming in the substomatal spaces, which would indicate that infection took place in that vicinity and presumably through the stomata. York³² found germ tubes of æciospores entering the stomata of leaves of *Ribes cynosbati*, *R. glandulosum*, and *R. nigrum*.

VARIATIONS IN APPEARANCE ON RIBES LEAVES.

The study of great numbers of *Ribes* leaves infected in the greenhouse and of very numerous specimens of diseased leaves collected in the field from Maine to Minnesota, during the past ten years, has revealed some distinct variations in the appearance of the fungus and of the diseased leaves of different species and varieties of *Ribes*. Previous study of such differences seem to have been made chiefly by Hennings (52, 53).

BLISTERY APPEARANCE OF THE UREDINIA.

In August, 1916, there occurred a very hot, dry period in New England. This was followed by the finding of a few very peculiar-looking uredinia on *Ribes nigrum* and *R. vulgare*. Under a hand lens, the uredinia were not of the usual mealy appearance, but looked more like tiny blisters. Examination showed that the epidermis of the leaves had become toughened, so that the uredinia did not burst through it, as they usually do, but pulled it loose from the inner leaf tissues and in this way actually formed small blisters. The urediniospores never broke through it. From the weather conditions preceding and at the time this occurred it is believed that the dry, hot weather rendered the epidermis tougher than usual. It is a rare occurrence, as only a few cases have been noted. In 1916, one specimen came from each of the States of Massachusetts, Maine, and Vermont. In 1917, a single case was found in New Hampshire. Hedgcock noted this in 1919 upon artificially inoculated *Ribes* bushes on Block Island. Recently, blisters have been noted on *R. aureum* and *R. fasciculatum* in the greenhouse.

³² York, H. H. Op. cit.

DISTRIBUTION AND SIZE OF THE SORI AND COLONIES.

It has been found that *Cronartium ribicola* forms its uredinia and telia upon each species of *Ribes* in a manner which in general is characteristic of that host species (Pls. IV; V, figs. 1, 3, and 4; and VI). This was noted in 1902 by Hennings (52, 53), who described some of the more striking variations. Like all general statements, the following are subject to individual variations from the normal or average condition for the host species. A statement by Hennings (52, p. 130) indicates the degree of variation discernible to a keen observer:

It is especially noticeable that the fungus, according to the character of the leaves of various species of *Ribes*, shows great variations in the form and color of the spots produced on the leaves, the form and size of the sori, and the size of the telial columellæ, so that a new observer would assume that several of the fungus forms were specifically distinct.

In general, on species which are closely related, or which closely resemble each other, the fungus behaves in a similar manner. Some of the more striking variations are described as follows:

RIBESIA.³³—*Ribes petraeum* and var. *atropurpureum*: Sori close together and evenly distributed over the spots; spots large, soon overrunning a large part of the leaf surface.

Ribes rubrum vars. *petrowalskyanum*, *pubescens*, and *sibirica*: Very scant sori, located beside large veins of leaf; var. *scandicum* has abundant sori, close together, generally distributed.

Ribes triste: Sori clustered on definite spots; spots small, widely separated.

Ribes vulgare: Sori not plentiful, clustered on spots; spots small and isolated (Pl. IV, fig. 3; V, fig. 4).

HERITIERA.—*Ribes coloradense*: Sori thickly clustered on diffuse spots.

Ribes glandulosum: Sori usually thinly scattered over large diffuse spots or entire leaf surface, telia very slender and long (Pl. VI, fig. 1).

Ribes erythrocarpum: Sori plentiful, clustered.

CALOBOTRYA.—*Ribes glutinosum*: Sori thickly clustered in local areas.

Ribes nevadense: Sori thickly grouped on local spots; spots large and distinct.

Ribes viscosissimum: Sori isolated, scattered over entire leaf surface.

SYMPHOCALYX.—*Ribes aureum* and vars. *tenuiflorum* and *palmatum*: Sori abundant, closely grouped in rather distinct spots which usually are well separated from each other (Pl. IV, fig. 1).

Ribes odoratum: Sori abundant, closely grouped in spots usually well separated from each other.

AROPHYLLUM.—*Ribes cereum*: Sori clustered on definite rounded spots which soon die.

Ribes inebrians: Sori on rounded spots.

EUCOREOSMA.—*Ribes americanum*: Sori sparse and scattered, on small irregular spots which redden and die; heavy infection rare; telia short, one-half to 1 mm.

Ribes bracteosum: Sori plentiful, on large diffused spots or patches of leaf surface.

Ribes nigrum (Pl. IV, fig. 4) and vars. *aconitifolium*, *fasciculatum*, "*folio argentea*": Sori crowded densely, often over entire leaf surface, vigorous; telia abundant, reaching 2 mm. in length.

Ribes viburnifolium: Sori scant, dead spots form early.

³³ The species of *Ribes* are grouped according to the arrangement of Janczewski (60).

GROSSULARIOIDES.—*Ribes lacustre*: Dead spots formed early on infected leaves: sori sparse or diffuse, irregular spots; telia rather scattered.

GROSSULARIA.—*Ribes lobbi*: Sori thickly crowded on rounded spots, telia well developed.

Ribes menziesii: Sori sparse on small irregular spots.

Ribes speciosum: Sori seated closely together on large rounded spots, telia rather short.

EUGROSSULARIA.—*Ribes alpestre*: Sori thickly crowded on large rounded spots, telia short.

Ribes curvatum: Sori crowded on rounded spots on young leaves, on irregular spots on old leaves; telia quite plentiful; spots with reddened edges late in season.

Ribes cynosbati: Sori plentiful on definite spots, which are usually rounded (Pl. V, fig. 1): spots sometimes wedge shaped, lying between two branching veins of the leaf; telia crowded in small groups, 1 to 1½ mm. long, rarely over entire leaf surface.

Ribes divaricatum: Sori scattered on rounded spots.

Ribes missouriense: Sori crowded on rounded indefinite spots on young leaves, densely crowded on small leaves, dead irregular spots on old leaves.

Ribes leptanthum: Sori very scant; dead spots appear so early that uredinia can form with difficulty, often only one uredinium on a spot, many spots without sori; produces the least sori of any species yet noted.

Ribes hirtellum: Sori usually crowded thickly on small spots; uredinia on small rounded spots; telia small, crowded densely; on older leaves, on small indefinite, irregular spots bounded by veinlets; spots sometimes purplish on the edges.

Ribes oxyacanthoides: Like *R. hirtellum*.

Ribes reclinatum: Sori rather sparse, on small irregular spots of dead tissue. There is a tendency toward a reddening or purpling of the edges of the spots on old leaves. (Pl. V, fig. 3.)

Ribes rotundifolium: Sori crowded on small irregular spots. The spots die early and are likely to become reddish around the edges even on rather young leaves. It is rather rare for the entire leaf to become covered with sori.

Ribes setosum: Much like *R. cynosbati*.

HEMIBOTRYA.—*Ribes fasciculatum* vars. *chinense* and *japonicum*: Sori densely crowded on large rounded spots.

DIACANTHA.—*Ribes diacantha*: Sori on rounded spots.

Ribes girdalii: Sori scattered on rounded spots.

In general, it may be said that *R. nigrum* and its varieties is the optimum host species among the *Ribes* for *Cronartium ribicola*. *Ribes aureum* and *R. odoratum* and their varieties are perhaps next to *R. nigrum* in favoring the growth of the fungus. *R. reclinatum* does not take the disease readily, but is by no means immune to it. In fact, no species or variety yet fully tested is entirely immune. *R. leptanthum* probably produces fewer sori for the extent of infection than any other species. This is caused by the very early death of the infected tissue.

PALE COLOR OF INFECTED SPOTS ON THE LOWER SURFACE OF RIBES LEAVES.

The production of sori on an infected spot on the lower surface of *Ribes* leaves is often preceded for one, two, or three days by a pale

coloration (Pl. VI, fig. 2). This is most likely to occur on young leaves. It is a fairly certain symptom of a successful inoculation.

Striking cases of the preservation of the normal green color in the infected areas, while the rest of the leaf is etiolated, have been noted a number of times.

PALE COLOR OF INFECTED SPOTS ON THE UPPER SURFACE OF RIBES LEAVES.

Numerous young *Ribes* leaves inoculated in the greenhouse developed pale spots on the upper side of the infected leaves (Pl. V, fig. 1). These varied from nearly white to yellow. Similar spots are often seen in the field. Some species of *Ribes* seem to be more likely to develop these spots than others. Among those showing this etiolation as a result of infection by *Cronartium ribicola* may be mentioned: *Ribes aureum* and its varieties, *R. cereum*, *R. cynosbati*, *R. divaricatum*, *R. erythrocarpum*, *R. fasciculatum*, *R. glandulosum*, *R. hirtellum*, *R. inebrians*, *R. inerme*, *R. leptanthum*, *R. nevadense*, *R. nigrum*, *R. odoratum*, *R. reclinatum*, *R. rotundifolium*, *R. setosum*, *R. speciosum*, *R. triste*, and *R. vulgare*. These spots seem to be produced by conditions existing in the immature *Ribes* leaf when attacked by the fungus very actively.

REDDENING OF INFECTED SPOTS ON RIBES LEAVES.

Certain species of *Ribes* react to infection by *Cronartium ribicola* by a reddish or purplish coloration around the edges of the infection. This is common with some species, while others apparently must have the leaves at a certain stage of maturity for this coloration to occur. *Ribes americanum*, *R. curvatum*, *R. rotundifolium*, *R. viburnifolium*, *R. glandulosum* (old thick leaves), *R. cynosbati* (old thick leaves), *R. hirtellum* (old thick leaves), *R. oxyacanthoides*, *R. reclinatum*, and *R. missouriense* develop the red color in the order named.

DEAD AREAS OF INFECTED LEAF TISSUE.

Where the attack of *Cronartium ribicola* is intense, areas of the oldest infected tissue of the diseased leaves collapse and die (Pl. V, figs. 3 and 4; Pl. VI, fig. 3). The different species of *Ribes* vary much in this respect, some developing dead spots very quickly and some doing so only after considerable time. *Ribes nigrum* usually resists death tenaciously. When a spot dies it is commonly a large one and soon results in the premature fall of the affected leaf. At the other extreme is *R. leptanthum*. With this species the infected spots die very quickly, even before uredinia can form (147). Less than 10 per cent of these spots produce any uredinia or telia, and those few spots bearing sori usually have only from one to several stunted sori. All species of *Ribes* tested have sooner or later developed dead spots. Just how much secondary fungi contribute to the killing of host tissues is entirely unknown.



LEAVES OF RIBES INFECTED WITH *CRONARTIUM RIBICOLA*, SHOWING DIFFERENT TYPES OF INFECTION.

FIG. 1.—Infected leaves of *Ribes glandulosum*, showing lower surfaces; the sparsely scattered telia are well distributed over the entire surface. Etiolation caused by the disease is also evident. $\times \frac{1}{2}$. FIG. 2.—Lower surfaces of leaves of *Ribes* sp., showing etiolated spots where infection has taken place, two days before uredinia were formed. $\times \frac{1}{2}$. FIG. 3.—Lower surfaces of infected leaves of *Ribes aureum*, showing the disease distributed in local spots mostly well separated from one another. On the right side of the right leaf a large area of leaf tissue has died. Etiolation from the disease is evident. $\times \frac{1}{2}$.

THE UREDINIA AND UREDINIOSPORES.

GENERATIONS OF UREDINIA.

In 1918, Pennington³⁴ and Snell investigated the number of generations of uredinia of *Cronartium ribicola* produced in the Adirondack region, and the weather conditions that might influence their production. *Ribes rotundifolium*, *R. cynosbati*, and *R. glandulosum* were the principal species used in these investigations. The observations were made in four different localities within 10 miles of the town of Lewis. There were seven periods of uredinial production in 1918. The first generation began on May 28, reached its climax about June 12, and then gradually fell off until June 26 to 28, when the second appeared. The third began to appear about July 12 and reached its maximum on July 19 to 22. The second and third crops of uredinia were located almost entirely on those leaves which were originally infected by æciospores or those adjacent to them. Drought from July 18 to July 28 caused most of the infected leaves to drop from the bushes of *Ribes cynosbati* and *R. rotundifolium*, leaving them partly or entirely defoliated. The fourth crop was much smaller, but well marked, and came on August 19 and 20. The fifth generation came on September 12 to 15; it would have been more abundant had not a heavy frost on September 11 killed all the leaves of *R. glandulosum* and some on the other two species of *Ribes*. The sixth crop appeared especially on the second crop of leaves of the earlier defoliated bushes and on fresh green leaves of bushes in sheltered situations. The seventh generation appeared on October 15 to 18 on leaves ready to fall. A study of the weather conditions, as noted at Lewis, showed that about two weeks before the appearance of each new generation there was a period of at least 24 hours of rainy and cloudy weather. But not all such periods were followed by new crops of urediniospores.

In 1919, Pennington³⁴ found that the generations of uredinia were not as distinct at Lewis, N. Y., as they were in 1918. The first four, on May 23, June 21 and 22, July 3, and July 20, respectively, were well defined. A fifth on August 7 and a sixth on August 21 were distinct on some bushes, but in most places overlapped. In general, after August 1, the generations overlapped, because of rain every day or two, so as to become confused with each other.

SEASON OF PRODUCTION OF THE UREDINIA.

Like the æcial season, the beginning of the uredinial season of production varies with conditions somewhat, though to a less marked degree. May 16 is the earliest recorded date for mature uredinia. A week after this is the more usual time for them to be found in most

³⁴ Pennington, L. H. Op. cit.

localities. (For range of observed dates in various sections of North America, see Table V, p. 72.)

In the White Mountain region of New Hampshire, York ³⁵ found fresh urediniospores in 1918 on May 16 and as late as November 17. Urediniospore production there continued on some bushes for 185 days, while under average conditions it continued about 120 days. At this place the following species were under observation: *Ribes cynosbati*, *R. glandulosum*, *R. lacustre*, *R. nigrum*, *R. odoratum*, *R. oxycanthoides*, *R. reclinatum*, *R. triste*, and *R. vulgare*. Urediniospore production continued the longest time (185 days) on *R. nigrum* and the shortest time (65 days) on *R. lacustre*. In general, it can be stated that the urediniospores continue to form as long as there are susceptible leaves on the *Ribes* bushes of a given locality.

York ³⁵ found that the maximum urediniospore production in 1918 occurred about July 14 to 16 and in 1919 about July 25 to 26. After these dates came the maximum sporidia production, and then the bushes became almost completely defoliated.

DISTANCE OF DISSEMINATION OF THE UREDINIOSPORES.

In the early work upon *Cronartium ribicola* in North America the wide dissemination of the fungus from a given center appeared to take place by means of the urediniospores. Stewart and Rankin (151), who had an especially good opportunity to study this point, concluded that the urediniospores were blown at least one-half mile. Early general observations of the spread of this stage indicated that a wet season greatly favored it, while a dry season just as markedly retarded it.

McCubbin (87) found that urediniospores fall in still air about 8 feet in 5 minutes. He calculated that a 30-mile breeze would carry them $2\frac{1}{2}$ miles in this time. Theoretically they may be distributed long distances if located on a hill or if picked up by convection air currents. But most of these spores are actually produced within 2 feet of the ground in most localities, so that they are not picked up by the wind as readily as the æciospores, which are commonly produced a number of feet above the ground. When set free, the urediniospores adhere in masses, so that they are not as readily blown by the wind as are the æciospores, which tend to fall apart when dislodged from the æcium.

York and Overholts (cited in Spaulding, 145) in 1918 at North Conway, N. H., found urediniospores in spore traps up to 300 yards distant from the known source. This was where rain was plentiful practically all summer. Observations on infections of *Ribes glandulosum* and *R. cynosbati* plants indicated that the disease spread by urediniospores up to 100 yards. In some cases where the bushes

³⁵ York, H. H. Op. cit.

were protected by surrounding trees or other objects, the rust spread little or not at all. In other words, where moisture was plentiful through the season, the distance of spread by urediniospores was governed by factors controlling the free access of the wind. In Essex County, N. Y., drought prevailed through July and August in 1918. Here Pennington³⁶ worked with spore traps and Snell (128) gave special attention to a study of the spread of the uredinial stage on *Ribes*. The *Ribes* of this section were largely *Ribes rotundifolium* and *R. glandulosum*. Here the rust spread in most instances only to adjacent leaves from those first infected on a given bush. The spore traps here caught urediniospores only at a very short distance, 50 feet or less.

In 1919, York (cited in Spaulding, 146) caught urediniospores up to a distance of 3,400 feet in an open location, but they did not germinate. Urediniospores caught at 3,200 feet did germinate. Pennington³⁶ caught urediniospores up to 156 feet.

AGENTS DISSEMINATING THE UREDINIOSPORES.

Wind has been supposed to be the principal agent distributing the urediniospores of *Cronartium ribicola*. While this supposition is correct in the main, other agents are concerned in the matter.

Hennings (53) says that sprinkling diseased *Ribes* plants with a strong stream of water carries urediniospores from plant to plant. Rain accompanied by high wind is known to carry spores of some plant diseases (38, 44). It is entirely possible for this to occur with any spore capable of wind distribution, as in the present case.

In 1917 Gravatt and Marshall (45) made studies in the experimental greenhouse at Washington, D. C. They found that weevils, snails, slugs, and sow bugs fed on the uredinia and telia of *Cronartium ribicola* on the diseased plants. The ingested urediniospores lost their viability to a large extent, but not entirely.

In the same year Gravatt and Posey (46), working at Kittery Point, Me., found that gipsy-moth larvæ feed quite freely upon leaves of *Ribes hirtellum* and *R. vulgare* and that in some cases the only infected leaves were those which had been partially eaten by insects, indicating that they carried the spores which infected the leaves. The insects were found carrying viable urediniospores on their bodies. There can be no doubt that these insects play an important rôle in the local distribution of this fungus within the gipsy-moth infested area.

Studies by Snell (127) at Lewis, N. Y., in 1918, show that a large number of insects visit *Ribes* plants during the season when the rust is present upon the leaves. The spore-laden insects were inclosed in chambers with the tips of *Ribes glandulosum* plants, and infection

³⁶ Pennington, L. H. Op. cit.

resulted in due time. Many of these insects are, of course, accidental visitors, but quite a number feed or breed upon the Ribes plants. All of those which frequent the Ribes bushes by preference may carry many spores of both uredinia and telia. Such insects would be most likely to spread the disease, since upon leaving one Ribes plant they would seek another, thus scattering the spores exactly where they could start new colonies of the disease. But the accidental visitors, in a locality where Ribes bushes are abundant, could also spread the spores locally, but in a much more indiscriminate manner, so that but a very small percentage of the spores would ever reach leaves of Ribes.

Aside from carrying spores on their bodies, some insects feed directly on the uredinia and telia and a few of the excreted spores are known to retain their viability. Still other insects may be leaf eaters and ingest the rust spores only accidentally. These would be of minor importance in spreading the disease.

At Lewis, N. Y., where the Ribes bushes overhang narrow cattle paths which wind through a heavy cover of blackberry, raspberry, and other low shrubs, observations by Pennington and Snell indicate that cattle, sheep, horses, dogs, and berry pickers may carry the urediniospores from an infected bush to neighboring healthy ones.

The remarks on the carrying of æciospores by automobiles, steam trains, and electric cars on page 36 apply also to some extent to the urediniospores.

GERMINATION OF THE UREDINIOSPORES.

The urediniospores of *Cronartium ribicola* have been generally found to be erratic in germinating. At one time excellent germination occurs; at another, none at all. In the greenhouse experiments it seems that urediniospores produced in newly formed uredinia have greater infective power than those produced later in the same uredinia. Such early urediniospores seem to give as good results as fresh æciospores. The former are usually produced in limited quantities while the latter are usually abundant. This results in a more liberal use of the latter, so that a fair comparison of the two is not possible from the usual inoculation work. Gravatt made comparative tests and concluded that æciospores and urediniospores from newly open sori were about equal in infective power. More such tests should be made before any conclusive statement is made on this point.

Gravatt and York found that newly matured urediniospores produced out of doors were decidedly more viable than older ones. This agrees with general experience in making inoculations in the greenhouse.

Gravatt found that cooling the urediniospores on ice stimulated germination. Uncooled spores gave 15 to 23 per cent germination

while ice-cooled ones of the same lot gave 25 to 54 per cent germination. Marshall found the same stimulating effect from a temperature of 23° F. upon urediniospores on *Ribes* leaves stored outside a window, as compared with those on leaves kept at room temperature.

Posey dried infected leaves of *Ribes nigrum* in the hot July sun for four hours. Urediniospores from these gave germination ranging from 3 to 45 per cent, with an average of 17 per cent. Spores from other leaves collected at the same time and dried inside in the shade gave 3 to 90 per cent germination, an average of 47 per cent. During dry, hot weather it has been found that the viability of the urediniospores out of doors is very low.

Duff (30), in studying the factors affecting their viability, found that exposure to bright sunlight reduces their germination, the ultra-violet rays being the destructive agent. Their viability appears to him to be low. Three days after collection less than 50 per cent germinated in distilled water. In about two weeks germination was negligible even when stimulated by cooling to 2° to 5° C.

Pennington³⁷ made germination tests of newly-matured urediniospores of *Cronartium ribicola* produced naturally in the vicinity of Lewis, N. Y., from early June until late in the autumn in hanging drops of tap water. During the first two weeks of June (frequent rain) the percentage of germination was high. From June 16 to 28 no tests were made. On June 29 and July 1 (rather dry) only 1 per cent germinated. After this time, many tests were made with spores from various localities. By July 14 (very hot alternating with some rain) less than one-third of 1 per cent germinated, and from July 22 to 26 (hot and dry) less than one-tenth of 1 per cent. Fresh yellow spores kept in an ice box gave no better results. On August 1 (rain July 29 and 30) 5 per cent germinated. After this (decidedly more rain) from 10 to 40 per cent germinated. The viability of these spores seemed to be greatly decreased by hot, dry weather and increased by cool rainy spells at the time they were produced. When the number of spores produced decreased because of hot, dry weather, their rate of germination also decreased and vice versa.

Doran (28) found that the limiting temperatures for the germination of urediniospores are: Minimum 8°, optimum 14°, and maximum 25° C. He calls attention to the fact that—

There is apparently a relation between the season when spores occur and their temperatures for germination. The aeciospores of *Cronartium ribicola* occur in the spring when the average temperature is lower than in the summer, the season of occurrence of the urediniospores of this fungus. The aeciospores of this fungus have a minimum temperature for germination, which is 3° C. lower than that of the urediniospores; an optimum 2° C. lower than that of the urediniospores; and a maximum 6° C. lower than that of the urediniospores.

³⁷ Pennington, L. H. ¹ Op. cit.

Germination of fresh urediniospores usually takes place readily in tap water. Gravatt found that distilled water gave poorer germination than tap water. Colley (20) found that the germ tube pushes through the exospore without the aid of a germ pore. The contents of the spore soon pass into the young germ tube, which may extend some distance over the surface of a *Ribes* leaf. Entry to the interior of the leaf appears to be through the stomata. The urediniospores germinate in about five and one-half hours (28) in drops of distilled water on glass slides.

During germination studies in 1918, York³⁸ occasionally found germinating urediniospores which formed secondary conidia. An investigation of the conditions causing their formation showed that newly formed urediniospores usually do not produce the secondary conidia in tap water, while old urediniospores were more likely to produce them. The following species produced them, the frequency increasing in the order named: *Ribes lacustre*, *R. cynosbati*, *R. vulgare*, *R. reclinatum*, and *R. nigrum*. Urediniospores from *R. glandulosum* did not produce secondary conidia. Urediniospores exposed in bags of mosquito netting out of doors gave especially abundant secondary conidia. Urediniospores from *R. nigrum* produced secondary conidia in weak solutions of ammonia, maltose, tannic acid, gallic acid, malt extract plus gallic acid, lactose plus tannic acid, and lactose plus gallic acid. They were especially abundant in the last solution. They were not produced in pine decoction, weak solutions of ether, lactose, maltose plus tannic acid, and maltose plus gallic acid. A limited number were produced in water. They form on the ends of the germ tubes or laterally and are capable of producing a germ tube themselves. Similar secondary conidia have been noted by Tulasne (175) in cultures of *Cronartium asclepiadeum*, and they have been noted by Plowright (109) and Sappin-Trouffy (122) in other Uredinales.

LONGEVITY OF THE UREDINIOSPORES.

The first experiments in testing the longevity of urediniospores of *Cronartium ribicola* seem to have been carried out by McCubbin³⁹ in 1916. His manuscript account of these experiments follows:

The spores used for this series were all collected on the same day. They were dried on paper for a few hours and then placed in a number of small bottles plugged lightly with cotton, the contents of each bottle being available for a single inoculation. Half of these bottles were kept on a shelf in the laboratory, where they were dry and exposed to weak light, and the other half were placed under a bell jar on the soil in a garden, exposed to changes of humidity, temperature, and light.

At stated intervals a bottle was taken from each set and the spores within were shaken up with a small amount of distilled water. By the use of a small atomizer the suspension of spores was then sprayed on the under side of the leaves of small

³⁸ York, H. H. Op. cit.

³⁹ McCubbin has very kindly allowed the use of his unpublished data so as to make this account as complete as possible.

currant plants which had been previously set out in an isolated garden for the purpose. After inoculation the plants were covered for two days by a box having a glass lid. In all cases, water was sprinkled three or four times daily on the plants and on the inside of the box, to keep a high humidity. Unfortunately, during the whole of the period covered by this series of inoculation the weather was exceedingly hot and dry, and it was evident from a study of field conditions that infections could take place at this time only with the greatest difficulty. The adverse nature of the weather conditions will serve to explain the meager results.

The only positive result from this experiment was that the spores would retain their power of infection for a period of nine days at least; but so many failures occurred all through the course of the work that this period can not be regarded as establishing a maximum limit of life.

It is interesting to note that the spores kept outside underwent a complete decolorization in two days, whereas those stored in the laboratory retained their normal color, with but little change throughout the whole time of the experiment.

The inconclusive results obtained from the first set of inoculations in the field led to another later attempt with plants kept in the laboratory, for this purpose a number of small plants being used from which the leaves had been stripped, so as to induce the formation of secondary foliage. The methods employed in this case were the same as for the first set, except that after inoculation the shoots were kept covered and moistened for the usual 48 hours inside large glass jars. (See Table IV.)

TABLE IV.—*Inoculation of currants with uredospores of different ages.*

Series.	Age of spores (days).	Date of inoculation, 1916.	Number of leaves used.	Date of examination, 1916.	Result.
I.....	2	August 31.....	16	September 19.....	5 pustules on 2 leaves.
II.....	4	September 2.....	16	September 22.....	67 pustules on 11 leaves.
III.....	7	September 5.....	16	September 25.....	No infection.
IV.....	8	September 6.....	14	September 26.....	10 pustules on 5 leaves.
V.....	11	September 9.....	11	September 29.....	8 pustules on 2 leaves.
VI.....	13	September 11.....	16	October 1.....	2 pustules on 2 leaves.
VII.....	18	September 16.....	5	October 6.....	No infection.
VIII.....	24	September 22.....	7	October 12.....	Do.
IX.....	27	September 25.....	7	October 15.....	Do.
X.....	31	September 29.....	7	October 19.....	Do.

The results from these inoculations were somewhat better than those from the first set; infections were obtained from spores kept for 13 days after collection, as shown in the tabulated record. It is still thought that this period is far below the maximum period for which the spores will retain their vitality.

In 1917 Gravatt and Taylor made a series of tests of urediniospores together with æciospores and teliospores. (See p. 38 for details of the experiment.) They were tested weekly beginning May 8. June 16 gave the last germination in lot A, while lot B persisted until July 2. Although germination persisted longer in lot B, it weakened decidedly somewhat earlier and was poorer practically throughout the test. (See Table II, p. 38.)

In 1918, Duff (30) experimented on the longevity of urediniospores placed in a refrigerator at 2° to 5° C. two weeks after collection and tested in hanging drops of distilled water. He states that when placed in the refrigerator—

A negligible percentage of spores were germinable, but reduction in temperature stimulated them to greatly increased germination. By this means a continually

decreasing percentage of spores were kept in a viable condition, until after a lapse of a further period of about three weeks the number that germinated readily was negligible once more. Before the end of four weeks the spores had ceased to germinate.

Extensive tests of the longevity of urediniospores were made by York, Overholts, and Taylor.⁴⁰ In one experiment leaves of *Ribes nigrum*, *R. vulgare*, and *R. reclinatum* were placed in bags of mosquito netting with the urediniospores outward. The bags were placed on three stakes at 6-inch intervals, the lowest one touching the ground and the highest 5 feet above the soil. The lowest spores remained viable only 6 to 9 days, while the upper ones were viable longest, 65 days. A 2-day rain began the day after starting the experiment and again a 1-day rain two days later. The urediniospores from *R. nigrum* remained viable longest. Again infected leaves of *Ribes nigrum*, *R. vulgare*, *R. cynosbati*, and *R. glandulosum* were put in open boxes and exposed for 4 hours to the early morning sun. Viability persisted only 15 days. The urediniospores from *Ribes nigrum* remained viable longest. Urediniospores on pulled bushes of *Ribes glandulosum* and *R. cynosbati* hung in the bright sun remained viable only 4 days. Spores on leaves of *Ribes nigrum* dried in a plant press, then put in tight Mason jars and stored in an ice-box remained viable 80 days. Successful inoculations were made with urediniospores collected 270 days previously and also with urediniospores from dead, overwintered leaves of the previous season. The age of the spores is not known, but they were certainly overwintered spores (180). It was found that viability in tap water persisted at least 169 days when the spore-bearing leaves were air dried and kept under slight pressure between sheets of heavy glazed paper. When kept out of doors but protected from rain, they retained viability for 100 days.

In 1918 Pennington⁴¹ made a number of tests of the longevity of urediniospores. In July and August urediniospores on *Ribes* leaves brought into the laboratory and air dried lost their viability within a week when tested in drop cultures of tap water. On September 25 many *Ribes* leaves were collected and allowed to dry between sheets of paper. The second day urediniospores from these leaves gave 50 per cent germination when tested as above. The leaves were left in the dry air of the laboratory. The spores decreased in viability until November 26 when but 1 per cent germinated. After that there was no germination.

These results, showing a longevity ranging from 7 to 270 days under varying conditions, indicate the sensitiveness of the urediniospores to external factors. In addition it is quite possible that the physiological condition of the host plant also has a profound effect upon these spores.

⁴⁰ York, H. H., Overholts, L. O., and Taylor, M. W. The longevity of the sporidia of *Cornartium ribicola*. Seen in manuscript. To be published in *Phytopathology*.

⁴¹ Pennington, L. H. Op. cit.

THE TELIA AND TELIOSPORES.

GENERATIONS OF TELIA.

In 1918 Pennington⁴² made observations upon the generations of telia at Lewis, N. Y. This was a season very favorable for the occurrence of distinct waves of spore production. The first generation of telia appeared on June 28 with and following the second crop of uredinia. They were present throughout the rest of the season, but in the greatest abundance with and immediately following a new generation of uredinia. As compared with the uredinia, they were produced in relatively greater abundance with each succeeding generation. There were six distinct waves of telial production.

SEASON OF PRODUCTION OF THE TELIA.

The date when the first telia are produced varies from year to year with the earliness of the season. The earliest of which we have definite record is June 2, 1918, at North Conway, N. H. Table V (p. 72) gives data for the different regions of North America. The telia are formed until the Ribes leaves fall in the autumn. Drought is likely to cause premature shedding of diseased Ribes leaves soon after the first telia form. This greatly limits the production of new telia.

DISTRIBUTION OF THE TELIOSPORES.

Because the teliospores are produced in more or less compact columellæ they are normally not separated from the host plant. They do become distributed somewhat, however. Gravatt and Marshall (45) found that slugs eat telial columns from rusted Ribes leaves; also that sow bugs carry broken columns on their bodies. There seems to be no reason why insects and other animals may not do likewise.

The telia are sometimes mechanically broken off and blown about by the wind.

Diseased Ribes leaves fall to the ground and are blown about by the wind. Often they are broken into small pieces which may be blown long distances. In fact, York⁴³ found such bits of dead leaves in his spore traps 200 feet distant from the nearest Ribes bush. Telia on dead leaves kept out of doors in the shade are known to retain viability for 65 days, so that in this way the disease might appear in very unexpected places on pines at a greater distance than the sporidia are carried in a viable condition.

GERMINATION OF THE TELIOSPORES.

The teliospores germinate readily in tap water and produce sporidia in 6 to 12 hours.^{43,44} Each spore produces normally a 4-celled pro-

⁴² Pennington, L. H. Op. cit.

⁴³ York, H. H. Op. cit.

⁴⁴ York, H. H., Overholts, L. O., and Taylor, M. W. Op. cit.

mycelium. Each cell regularly puts forth a stout sterigma on which the very thin walled, globular sporidium soon develops. The sporidium has a tiny papillalike swelling where it was attached to the sterigma. The sporidia are 8 to 10 microns in diameter (20). The germ tubes of the teliospores, if developed under water, may not form promycelia but extend elongated hyphæ (20). Under favorable conditions a high percentage of the teliospores may germinate, but because of their aggregation into columellæ it is impossible to make an exact count of the germinating spores. Cooling on ice stimulates viability markedly.

LONGEVITY OF THE TELIOSPORES.

The longevity of the teliospores of *Cronartium ribicola* does not seem to have received as much attention as that of the æciospores and urediniospores. Gravatt and Taylor made tests with teliospores in 1917 similar to those described as made by them with æciospores and urediniospores. (See Table II.) Weekly tests showed that germination persisted in lot B 35 days, while it lasted 56 days in lot A. Saprophytic fungi attacked the lot kept on the window sill, so that the test probably does not show the longevity of healthy teliospores.

York ⁴⁵ in 1918 found that teliospores were still capable of germination in tap water after being kept on the plucked leaves 65 days out of doors in the shade. A similar test of teliospores kept in the dark in the laboratory gave germination for 90 days.

THE SPORIDIA.

SEASON OF PRODUCTION OF THE SPORIDIA.

The sporidia may be produced as soon as the telium is mature, if there is sufficient moisture in the air for a number of hours.

The telia may remain alive on dry dead leaves out of doors for more than 65 days, so that sporidia might be produced well into the winter in mild seasons, thus prolonging the danger season for pines.

DISTANCE OF DISSEMINATION OF THE SPORIDIA.

In work with spore traps by Pennington ⁴⁶ and Snell in 1918, sporidia were caught up to 60 feet from very heavily infected *Ribes* bushes. This was in the eastern Adirondacks, about 8 miles from Lake Champlain. Hundreds of pines were examined for infections. In no case was infection found on pines as far as 200 feet from *Ribes* plants. Pennington made a study of nine outbreaks in pines in the Adirondacks. The infection on pines was confined to an area within 100 to 200 feet of the *Ribes* plants which infected the pines.

⁴⁵ York, H. H. Op. cit.

⁴⁶ Pennington, L. H. Op. cit.

In 1919, Pennington (cited in Spaulding, 146) caught sporidia up to 294 feet distant, but they failed to germinate. Under favorable conditions, sporidia caught at a distance of 177 feet germinated, but none beyond this distance.

York,⁴⁷ working in the White Mountain region of New Hampshire, in 1918, found that sporidia were quite common in spore traps exposed 24 hours at a distance of 200 feet from the diseased *Ribes* bush. York (cited in Spaulding, 146) in 1919 caught sporidia, under favorable conditions, at 600 feet distance, which germinated.

The infection of pines is said by McCubbin (88) to depend on “(1) The nearness of cultivated *Ribes*, particularly black currants; (2) the number of wild *Ribes* present; (3) the moistness of the situation.” York⁴⁷ concluded that these factors are “topographical features, direction of the wind when sporidia are produced, humidity of the air, precipitation, and the nature and density of vegetation between the *Ribes* and pines.” Pennington⁴⁸ stated that weather conditions have much to do with the degree of infection that occurs on pines; cool, moist situations favor infection; intervening barriers of vegetation tend to limit infection; the amount of infection under given conditions varies directly as the extent of *Ribes* leaf surface and inversely as the square of the distance from *Ribes*. The writer (145) said the width of the *Ribes*-free zone around pines is largely to be governed by topographical features; direction of the wind prevailing at the time the sporidia are produced; humidity; age of the pines; exposure and species of *Ribes*; and the composition, height, and density of the vegetation between the *Ribes* plants and the pines. The experiments with the sporidia show that high humidity is necessary for these spores to live any length of time. It alone may very largely determine whether infection can take place.

A few specific instances show the effect of these factors in actual outbreaks. On July 10, 1917, on Gerrish Island, at Kittery Point, Me., Gravatt investigated the small trees of *Pinus strobus* within a radius of 15 feet of a bush of *Ribes hirtellum* to determine the spread of infection. The gooseberry was a small bush, having approximately 270 small leaves and there were no other *Ribes* near by to influence the result on pines. The ages of the pines were as follows: Two years, 12; 3 years, 17; and 5 years, 82; a total of 128 pines, none over 5 years of age. There were 77 separate infections on 54 diseased trees, 44 of these infections being on 2-year wood. As the oldest pines were 5 years old and most of the infections which occurred the year before were probably not detected, this infection of more than 40 per cent resulted from an exposure of only a little more than

⁴⁷ York, H. H. Op. cit.

⁴⁸ Pennington, L. H. Op. cit.

3 years to the disease. To judge from the results of the first five years, it is not likely that any of the pines within the 15-foot radius would remain alive at the end of 12 or 15 years. Pines outside the 15-foot radius from the bush showed only scattering infections. This was in a location well protected from strong winds.

In another case where *Ribes nigrum* was well exposed to the strong storm wind from the neighboring White Mountains, York found pine infections up to 600 yards distant from heavily diseased *Ribes* bushes.⁴⁹

In the outbreak at Kittery Point, Me., Posey found that a number of *Ribes nigrum* bushes so located that the wind had moderate access to them caused infection of *Pinus strobus* trees up to a distance of about 300 yards.

Our studies (146) of the distance of distribution of the various spore forms and of the distance that infection has actually occurred upon pines from known infected *Ribes* indicate that the *Ribes*-free zone should be, under average conditions, 200 to 300 yards in width. It should be much more where conditions are exceptionally favorable for transfer of the spores from *Ribes* to pine, i. e., near large bodies of *Ribes*, where there is no screen of vegetation over the *Ribes* or between the *Ribes* and the pines, or in exceptionally humid situations. The cultivated black currant (*Ribes nigrum*) should not be allowed in an infected pine district because of the special danger from it.

Studies by York⁴⁹ of the natural infections of pines show that the sporidia are blown along roads cut through heavy forest cover and that they do not reach pines located in isolated small pockets in the dense forest. Trapping of sporidia from *Ribes* located under dense cover of black alder yielded sporidia only up to a distance of 75 feet. Traps set 20 feet in the air and well above the cover, but directly over the *Ribes* bushes, caught no sporidia.

AGENTS DISSEMINATING THE SPORIDIA.

It is apparent that the sporidia produced by the teliospores of *Cronartium ribicola* are largely disseminated by the wind. Observations in various areas where white pines have become infected from neighboring *Ribes* bushes show plainly that this is the case. In such cases the infection is most intense nearest the *Ribes* bush acting as a center of infection. The degree of infection decreases as the distance from the center increases. Other conditions being equal, the distance of pine infections from the infection center is very short where there is a thick screen over and around that center, while the converse is true where the *Ribes* infection center is well out in the open. (See pp. 64 to 66 for data bearing on this matter.)

Minor disseminating agents are known, and their number will undoubtedly be increased by future investigations. The investigations of Gravatt and Marshall (45) in the experimental greenhouse

⁴⁹ York, H. H. Op. cit.

at Washington, D. C., showed that weevils, snails, slugs, and sow bugs feed on the telia. The voided teliospores retained viability in a few instances. This indicated that similar animals might be active agents in the local distribution of these spores out of doors. Investigations by Snell (127) in 1918 at Lewis, N. Y., showed that a number of different types of insects feed on rusted leaves of *Ribes* bushes and may serve as carriers of the sporidia directly from plant to plant, or indirectly by the voided teliospores. Marshall, in 1917, found that the moist sporidia allowed to dry on a feather are not easily dislodged therefrom, either by wind or by brushing of the feather on cloth. This suggests the possible carriage of sporidia by migrating birds in the fall for long distances. Their very short life, as determined by York (see pp. 67-68), however, probably prevents their causing infection of pines under these conditions.

The remarks on the carriage of aeciospores by currents of air generated by fast-moving automobiles, steam trains, and electric cars also apply to the sporidia. (See p. 36.)

GERMINATION OF THE SPORIDIA.

Gravatt, Colley (20), and York, Overholts, and Taylor⁵⁰ found that the sporidia germinate immediately in tap water under favorable conditions. They germinate like ordinary fungus conidia, by pushing forth a germ tube which is relatively large. They are capable of germination as soon as they reach full size, even though still attached to the promycelium. The germ tube normally develops until a mycelium is formed. In some cases the germ tube soon forms a secondary sporidium which in turn may germinate. The viability of the fresh sporidia is high, as many as 90 per cent germinating within 24 hours.

LONGEVITY OF THE SPORIDIA.

The sporidia of *Cronartium ribicola* are so thin walled, and fragile in character that it seems self-evident that they are short-lived spores. This supposition has been proved to be correct by the work of York and Overholts in the summer and autumn of 1918 and of York and Taylor in 1919 (cited in Spaulding, 146). Colley (20) found in 1917 that fresh sporidia germinated readily in distilled-water cultures. York, Overholts, and Taylor⁵⁰ dried the sporidia on glass slides and tested their viability after varying intervals. Very slight germination resulted after 10 minutes exposure by an open window at 66° F. when light rain was falling. None survived when exposed to bright sunlight for 10 minutes with a temperature of 77° F. Nor did they survive when pieces of *Ribes* leaves bearing the telia and sporidia were exposed to sunlight for 10 minutes at 85° F. and with a humidity

⁵⁰ York, H. H., Overholts, L. O., and Taylor, M. W. Op. cit.

of 30.5 per cent. In another experiment the sporidia were placed on the periderm of white-pine twigs of the same season's growth and on living leaves of *Pinus strobus* and *P. rigida*. They were then exposed dry at 66° F. and with a humidity of 90 per cent. None survived for 10 minutes. At 72° F. and a humidity of 69 per cent none survived for 10 minutes. They conclude that the sporidia can endure very little desiccation and are short lived under seemingly optimum conditions. Abundant moisture is necessary for infection of pines to occur.

HETERÆCISM OF THE SPORIDIA.

A number of tests have been made to learn whether *Ribes* might become infected by sporidia of *Cronartium ribicola*. Jaczewski (59) states that experiments have shown that they will not infect *Ribes* leaves. In 1913, Clinton, Stewart, and the writer (151) inoculated *Ribes nigrum* leaves with teliospores overwintered out of doors, but there were no infections. In 1912 the writer tested fresh teliospores without infection occurring (136). In 1917 Gravatt made several tests of fresh, sporidia-producing telia, but no infection resulted.

OVERWINTERING OF CRONARTIUM RIBICOLA.

Overwintering on Pines.

The generally accepted view has been that *Cronartium ribicola* lives over winter by means of the mycelium in the bark of living infected pines and by this means only (142). A number of writers have mentioned cases where their observations seemed to indicate the possible overwintering on infected *Ribes*, but nothing that could be accepted as real evidence was offered until the last few years. There is no question that the fungus overwinters chiefly in the infected living pine trees and has been carried in the dormant condition from continent to continent in young infected pines.

It has been discovered, as has been mentioned earlier, that *Cronartium ribicola* may overwinter as mycelium in infected branches cut from diseased trees late in the fall, or during the winter, and allowed to lie until spring. Then, if these cut-off branches lie close to damp soil or with the cut ends in a stream or pool, fresh vigorous æcia are produced (89). Still another phase of overwintering was discovered by Dosdall (29) in Minnesota. On April 19, 1918, a dead branch of white pine, bearing an infection which bore æcia in 1917, was collected. Germination tests in distilled water showed that 1 to 2 per cent of the old æciospores were still viable.

Overwintering on Ribes Plants.

Investigations of overwintering of *Cronartium ribicola* on *Ribes* plants, in Europe, seem to be limited to field observations. They

relate to instances where diseased *Ribes* bushes were found widely separated from *Pinus strobus* or from all 5-leaved pines (6). These necessarily depend for reliability upon the observer's complete and minute knowledge of the *Ribes* and pines within considerable areas. Hence, such observations are of very uncertain value. Investigations showing that the æciospores of this fungus are distributed for miles largely invalidate such observations so far as overwintering is concerned.

In North America, investigations of overwintering on *Ribes* plants have been along the following lines: (1) By means of spores adhering to dormant *Ribes* plants, (2) in dormant or partially opened *Ribes* buds, (3) in living *Ribes* leaves which themselves lived over winter, (4) on dead *Ribes* leaves, and (5) on infected *Ribes* stems.

Overwintering by means of spores adhering to dormant *Ribes* plants has been investigated in several ways. A great many field observations have been made upon bushes diseased heavily one year and not infected the succeeding year. Cases where bushes were shipped from known diseased localities and have shown the rust the next season in their new locations, have been considered, but the evidence has been too incomplete to be seriously considered except as it might help to confirm or refute other stronger evidence. A great many *Ribes* plants have been used by the writer in greenhouse experiments; they shed their leaves and become dormant for several months, yet there has been no hint of the carrying over of the fungus upon them from one season to the next. A cooperative experiment was made with Stewart (151), using 500 plants of *Ribes nigrum*, which in the summer of 1912 were heavily infected. The leaves dropped normally. They were then dug and most of them heeled in out of doors until February, 1913. They were then brought into greenhouses in six widely separated localities and allowed to put forth new leaves. Examination of some of these dormant plants by Arthur and Petry showed that plenty of urediniospores still adhered to the stems and buds. Inoculations with these spores did not give any infection, so that they presumably had lost their viability. The results reported by six different investigators showed no infection appearing on the new leaves.

Howitt and McCubbin (56) in attempting to solve the overwintering problem, made the following tests:

(1) In the fall of 1914, 16 black and 7 red currant bushes and 1 gooseberry bush, all badly rusted, were stripped of leaves and placed in cold storage, where they remained until March 16, 1915. At this date they were removed and planted in a greenhouse. All grew well and produced healthy leaves and fruit and were entirely free from rust throughout the summer. In addition, 17 black currant bushes, which had been badly rusted in 1914 and which were wintered in the field, were added to the above on April 21, 1915. These also grew normally and without rust.

(2) Seventy-eight black currant bushes, badly rusted in 1914 were wintered in the nursery rows, and transplanted April 12, in various gardens, isolated as far as possible from infected white pines and currants. These were inspected six times during the summer, the last inspection being made on October 2. At this date all were still free from rust except two bushes, on each of which a few rusted leaves were found. There is reason, however, to suspect that these infections might have been due to spores carried from currants about a mile distant from the garden in which they occurred. In no case was rust found on any of these currants which were located more than a mile from a source of infection.

(3) A number of bushes from the same source as No. 2 were planted in five lots in a region known from personal observation to have been entirely free from the rust in 1914, and which is 60 miles from the nearest known source of infection. Of the 100 bushes set out here only one developed rust, and this late in the season. All conceivable sources for this infection have been accounted for except two, viz, the wintering over of the rust on the currant itself, or accidental infection from spores carried on the writer's clothing while making an inspection on May 24.

In 1917, V. B. Stewart (152) tested the possible overwintering of the fungus by means of spores adhering to diseased bushes of *Ribes nigrum*. These were heavily infected in 1915 and 1916. In August, 1916, they were defoliated, and 200 were dug and placed in a storage cellar in October, where they remained all winter. In 1917, they were sent to Ithaca, N. Y., and set out in a field. The disease had not been known within 40 miles. The disease did not appear upon them up to October 9, 1917.

The possibility of overwintering in *Ribes* buds was brought to the writer's attention by infections of petioles (131, 134, 135), by which means it seemed entirely possible for the mycelium to travel from a leaf blade down the petiole and thence into the stem and bud in the axil of the leaf. While many diseased petioles have been examined, no indication of the migration of the hyphæ into the stem or bud has yet been seen. Direct examination of buds on heavily infected bushes has also failed to yield any indication of bud-scale infection (151). McCubbin (85) suggested but could not prove that infection of partially opened buds late in the fall might result in some of the infected leaflets surviving the winter and developing the disease the next spring. York⁵¹ successfully inoculated the inner bud scales of opening buds of *Ribes nigrum* with æciospores, suggesting overwintering in this way.

The possibility of green leaves living over winter on *Ribes* plants out of doors has been investigated. In three cases, the writer had *Ribes* plants growing in pots plunged in sand out of doors at Washington, D. C., retain green leaves through the winter until the spring weather of March, 1918, set in. One plant of Cumberland gooseberry and two plants of Utah Yellow currants did this. They were taken as specimens on March 22, when warmer weather set in. The

⁵¹ York, H. H. Op. cit.

previous winter a single seedling plant of an unknown species bore leaves flat on the soil under similar conditions until March 12, 1917, when it was brought into the greenhouse and inoculated. It promptly took the disease on the overwintered leaves. York⁵² found *Ribes glandulosum* plants in the spring of 1918 which bore overwintered leaves that later became infected naturally. In such cases, it would be easy to understand that late infections in the fall might lie dormant until spring and then produce vigorous uredinia. More time is necessary to determine whether this actually occurs.

As stated previously, infection of petioles by *Cronartium ribicola* is quite common. Early in 1917 Colley (17) discovered that infected petioles often had telia and masses of active mycelium as well as uredinia in the central pith. This raised the question of the possibility of such mycelium remaining active until spring and producing new uredinia.

Whether the fungus can live over winter on dead diseased leaves seemed unlikely in view of the negative results of Arthur and Petry (151) with urediniospores from stems of plants diseased the preceding summer, and the negative results of Stewart (151) with material overwintered out of doors at Geneva, N. Y. Howitt and McCubbin (56) early in 1915 attempted to produce infection by spores which remained over winter out of doors on dead *Ribes* leaves. All of their attempts were unsuccessful. In the spring of 1918 York (180) and the writer obtained infections with urediniospores overwintered out of doors in Massachusetts on dead *Ribes* leaves, proving that urediniospores may survive the winter. This was repeated in the spring of 1919 by Taylor (157).

The possibility of infection on *Ribes* stems was early investigated by the writer but with no success. Many inoculations were made on young *Ribes* shoots by the writer and later by Gravatt, Doran (28), and York⁵² but without success. However, in the summer of 1917, Posey and Gravatt (112) discovered fruiting uredinia on the young shoots of *Ribes hirtellum* at Kittery Point, Me. They inoculated other young shoots with æciospores and secured mature uredinia. Colley found uredinia in the pith of these infected stems. Gravatt later inoculated young seedlings of *Ribes fasciculatum* in the greenhouse with æciospores and secured heavy infection of the cotyledons. In one seedling the fungus also attacked the stem just below the diseased cotyledons and developed several uredinia (Pl. V, fig. 2). Later, however, the plant outgrew the disease. Taylor and York have successfully inoculated stems of several species of *Ribes*. (See p. 50.)

That *Cronartium ribicola* overwinters on *Ribes* is established.

⁵² York, H. H. Op. cit.

IMPORTANT DATES IN THE LIFE HISTORY OF CRONARTIUM RIBICOLA.

Table V shows some of the more important dates in the development of the white-pine blister rust and their variation according to locality. These dates are rarely the earliest or latest possible ones, but are based upon notes actually made respecting the point covered. It is hoped to extend this table greatly and approach nearer the actual date when each stage of development is reached by the fungus in the various regions. Southern New England is here made to include Massachusetts, Connecticut, and Rhode Island. Northern New York is understood to include approximately that part of the State lying north of a line between Glens Falls and Oswego. The Lake States include Michigan, Wisconsin, and Minnesota. Similar data for Europe are given in the last columns of the table for the sake of comparison.

TABLE V.—*Important dates in the life history of Cronartium ribicola, as observed in America and in Europe.*^a

[To economize space, the century digits 19 are omitted in noting the year of each observation; thus '09=1909.]

Development noted.	United States.					Europe.	
	Southern New England.	Southern New York, New Jersey, and eastern Pennsylvania.	Northern New England.	Northern New York.	Lake States.	Date.	Locality. ^b
First closed blisters.....	Apr. 7, '17	Apr. 30, '11	Apr. 15, '10	Apr. 26, '18	May 5, '17	Apr. 16, '90	H
	Apr. 5, '18	Apr. 28, '17	Apr. 7, '17	Apr. 21, '19	Apr. 19, '18	Apr. 15, '01	M
	.....	May 4, '18	May 13, '18	.....	Apr. 18, '19	Apr. 7, '09	D
First open blisters.....	.....	.....	.....	.....	.....	Mar. 17, '18	F
	June 22, '09	June 1, '09	June 14, '09	June 8, '09	May 24, '16	Apr. 15, '90	H
	May 22, '11	July 27, '10	May 26, '10	May 12, '10	May 8, '17	.....	Bo
	May 16, '12	May 5, '11	June 9, '11	Apr. 26, '18	Apr. 19, '18	Apr. 29, '96	S
	June 3, '13	June 10, '13	May 15, '12	Apr. 23, '19	Apr. 22, '19	Apr. 28, '08	B
	May 25, '14	May 20, '15	June 6, '13	.....	.....	.....	.....
	June 2, '15	Apr. 7, '16	May 15, '15	.....	.....	.....	.....
	May 3, '16	Apr. 28, '17	May 15, '16	.....	.....	.....	.....
	Apr. 17, '17	May 16, '18	Apr. 29, '17	.....	.....	.....	.....
	Apr. 7, '18	.....	Apr. 23, '18	.....	.....	.....	.....
	Mar. 28, '19	.....	Apr. 7, '19	.....	.....	.....	.....
							
Last yellow blisters.....	.....	.....	June 7, '10	June 12, '18	June 24, '17	May 15,	H
	.....	.....	July 1, '17	June 26, '19	June 24, '19	May 9,	D
	.....	.....	July 21, '18	.....	Sept. 16, '19 ^c	June 1,	Bo
First uredinia .....	.....	.....	.....	.....	.....	May 19, '18	F
	June 3, '16	June 10, '13	July 24, '13	July 25, '09	June 9, '16	May 23,	D
	June 13, '17	July 18, '16	July 14, '14	July 18, '16	June 12, '17	May 30,	B
	May 29, '18	.....	May 20, '17	June 28, '17	May 18, '18	May 26,	B
	.....	.....	May 16, '18	May 16, '18	June 5, '19	June 2, '19	S
	.....	.....	May 23, '19	May 23, '19	.....	.....	.....
First telia	June 17, '16	.....	June 26, '13	Aug. 23, '17	July 21, '16	Aug. 1,	B
	July 21, '17	.....	July 24, '16	June 26, '18	June 12, '17	July 30,	M
	June 19, '18	.....	June 10, '17	June 30, '19	July 8, '18	.....	S
	July 30, '19	.....	June 2, '18	.....	July 10, '19	.....	.....
	.....	.....	June 6, '19	.....	.....	.....	.....
First pycnial drops.....	June 21, '16	.....	July 26, '13	July 3, '18	.....	June,	H
	June 7, '18	.....	June 7, '18	June 26, '19	.....	.....	.....

^a Notations for Ontario, Canada: First open blisters—May 10, 1917, and June 22, 1918; first uredinia—June 24, 1915, and July 20, 1916; first telia—June 24, 1915.

^b Abbreviations used: B=Berlin, Bo=Bohemia, D=Denmark, F=France, H=Hamburg, M=Munich, S=Silesia.

^c This date is an extraordinarily late one for telia to be formed, but it is included here to show the possibility of the aecial season being prolonged throughout the summer.

CONTROL OF THE WHITE-PINE BLISTER RUST.

Significant Factors Which Determine Control.

FACTORS IN THE FUNGUS.

The significant features in the life history of *Cronartium ribicola* are as follows: The pycnospores are apparently functionless; the æciospores are not known to infect pines, but they do infect *Ribes* readily; the urediniospores are not known to infect pines, but they do infect *Ribes*; the sporidia produced by the teliospores are not known to infect *Ribes*, but they do infect pines.

The spores are all distributed by the wind much more than by any other agency. The æciospores are carried and are capable of infecting *Ribes* leaves miles away from their source. The urediniospores are distributed a number of hundred yards, but appear to lose their viability soon, so that infection by them is rather limited in extent. The sporidia produced by the teliospores appear to be distributed to a distance of a few hundred yards, but they are so frail that they soon lose viability. Infection by them is limited to 100 to 600 yards as a general thing, and more commonly the former than the latter distance.

The fungus lives over winter most commonly by means of the mycelium, presumably in the needles and certainly in the bark of infected white pines. It occasionally overwinters by means of the æciospores in cankers of pine bark or by the urediniospores on *Ribes* leaves. The æciospores produced by the overwintered mycelium in the pine bark are the principal source of infection of the *Ribes* leaves each spring. The æciospores carry the disease far and wide for miles to the new *Ribes* leaves. The urediniospores intensify the disease in the vicinity where it is started by the æciospores. The sporidia carry the disease back to those pines which are relatively near infected *Ribes* bushes.

High humidity of the air is necessary for any of the spore forms to germinate and to produce infection.

FACTORS IN THE ENVIRONMENT.

CLIMATIC FACTORS.

Climate may be reduced to the three most potent factors—moisture, sunshine, and wind. *Cronartium ribicola* is absolutely dependent upon abundant moisture for its development. Drought, especially if prolonged, apparently may hinder the development of the æcia (49, 135). Lack of moisture prevents germination of all the different forms of spores. It prevents or very greatly reduces the extent of infection on *Ribes* plants by æciospores. It prevents the production of new generations of urediniospores,⁵³ and consequently prevents the abundant formation of uredinia as well as

⁵³ Pennington, L. H. Op. cit.

restricts the spread of this stage of the fungus. Moreover, drought very largely reduces viability of the urediniospores.⁵⁴ With the very short-lived sporidia of the teliospores it is evident that lack of moisture immediately after their production may entirely prevent their infecting pines at all, and drought is known greatly to limit their formation. Drought causes the premature fall of leaves of Ribes bushes so as to leave practically nothing for the fungus to subsist upon late in the season. Thus the crop of teliospores is so greatly reduced in times of drought that infection of pines is largely or entirely prevented. Drought kills many young Ribes seedlings and many are winterkilled (23, p. 8). On the other hand, rain undoubtedly beats down the spores floating in the air and washes spores from the host plants, so that infection by them is prevented.

Sunshine, by influencing the moisture of the air, may be very potent in reducing the activities of the fungus. It has a direct deleterious effect upon the spores⁵⁴ (30, 88). It is an open question whether the erratic germination of the urediniospores is not due to this action of the sun's rays. By promoting the quick maturity and hardening of the leaves of Ribes in the open, bright sunlight may greatly reduce the infection which develops upon them.

Wind is apparently the chief agent disseminating all forms of spores of this fungus. Its activity greatly influences the spread of the disease.

THE AGENCY OF MAN.

Man is a most potent agent in the dissemination of the white-pine blister rust. Through his activities it has made all of its known long-distance jumps. There is reason to believe that it is a native of northern Asia, whence it spread to Europe. The extensive trade in young trees of *Pinus strobus* is known to have been the means of introduction of this disease to many parts of Europe (111, 120, 155, 162, 170). It certainly came to North America in young white-pine stock from Europe and has attained its present wide distribution here in such imported stock. See figures 2 to 12, showing the progress of the disease since 1909.

INSECTS AND OTHER ANIMAL FACTORS.

Various animals (insects, snails, mammals, man, etc.) may aid in the distribution of the disease by carrying spores on their bodies, or they may retard or reduce the fruiting of the fungus by eating the sori on both pines and Ribes; and others such as gipsy-moth larvæ, other insects, snails, and squirrels may even eat the surrounding bark on pines, so that no more sori can form. (Pl. III.) In 1918, Pennington⁵⁴ estimated that the production of æciospores in the Adirondacks

⁵⁴ Pennington, L. H. Op. cit.

was reduced about 15 per cent by the eating of infected bark by mice, squirrels, porcupines, etc. Posey and Gravatt⁵⁵ found that squirrels had eaten 17 per cent of the æcia-bearing bark in a given area at Kittery Point, Me., and this is substantially true for the infected forests of that section. The leaf-eating insects and mammals may so reduce the leafage of *Ribes* plants as to reduce the disease materially in a given locality.

OTHER FUNGOUS FACTORS.

Other fungi are of some importance also. At Kittery Point, Me., Colley (20) and Posey and Gravatt⁵⁵ found that secondary fungi work in the pine bark infected by *Cronartium ribicola* in such a way as nearly or entirely to kill out the latter, probably by killing the bark around the cankers so that the blister rust is starved out. This sort of thing is quite general where white pines are generally infected by *Cronartium ribicola*. Very often it appears that the diseased pines are killed finally by the secondary fungi rather than by the blister rust. The æcia of *Cronartium ribicola* are sometimes attacked directly by other fungi (80, 168, 172). It has also been found that the uredinia and telia are attacked by various fungi, so that their efficiency is greatly reduced locally (116). Fungi parasitic upon the leaves of *Ribes* sp., causing their premature fall, may greatly reduce the leafage available for the blister-rust fungus to attack and thus reduce the quantity of teliospores to produce infection on pines.

FACTORS IN THE HOSTS.

There are certain factors in the hosts themselves which are important in the control of this disease where it has once become established. These are resistance by some of the hosts to the disease and the natural suppression of the lower branches of white pines.

Among the white pines the blister rust attacks *Pinus strobus* with especial virulence. It does not attack *P. cembra* nearly so readily. Experience shows that *P. flexilis*⁵⁶ is decidedly susceptible to it. This is confirmed by Moir's studies in Sweden. Knowledge of the relative susceptibility of the pines is extremely limited, because the disease has been in North America too short a time and has not yet reached any but the eastern white pine. In Europe, where the older outbreaks have occurred, there undoubtedly is an opportunity to obtain definite data on the relative susceptibility of the pines. It may prove feasible ultimately to plant another species of white pine which is not nearly so susceptible to the blister rust and which also is of value as a timber tree.

⁵⁵ Posey, G. B., and Gravatt, G. F. Field studies on the white-pine blister rust at Kittery Point, Me. Seen in manuscript.

⁵⁶ Pennington, L. H., Snell, W. H., York, H. H., and Spaulding, P. Investigations of *Cronartium ribicola* in 1920. Seen in manuscript. Published in *Phytopathology*, v. 11, p. 170-172. 1921.

It has been possible to learn a little more concerning resistant species and varieties of *Ribes*. *Ribes alpinum* is found to be immune in America, although it is stated that it takes the blister rust in Europe. There does not appear to be any resistant species which will take the place of the cultivated *R. nigrum* (the black currant), or of *R. odoratum* (*aureum*) (the flowering currant). Among the cultivated red currants the varieties Franco-German, London, Rivers, and Holland have shown themselves very resistant. In generally infected areas these may prove of value to replace the more susceptible varieties.

In the outbreak area at Kittery Point, Me., one of the oldest in North America, the infected pines are thickly crowded together and mostly range in height from 15 feet upward. The lower branches are being suppressed and are dying rapidly from overcrowding. Experience has shown that trees and branches attacked by the blister rust are weaker than healthy ones and are more apt to die from drought and suppression. Posey and Gravatt⁵⁷ find that this natural suppression of lower branches at Kittery Point has resulted in the killing of many entire branches bearing blister-rust cankers well out from the trunk of the tree. In such cases the disease in the dead branches is killed also. They find that about 15 per cent of the trees originally infected have thus recovered from the disease before it reached their trunks. As above intimated, this process is probably at its height in this area, since suppression of the branches is apparently at its maximum.

Experiments in Control in Europe.

In experimenting with the white-pine blister rust, the European investigator has always had a different viewpoint from that of the investigator in North America. This has been due to two reasons—the disease was possibly native in Europe, certainly in Asia, but was introduced into North America; *Pinus strobus*, the favorite pine host for the fungus, is native in North America and introduced into Europe. That is, the situation is exactly reversed in every respect in North America as compared with Europe.

The disease is generally considered to have been native in the Alps and in the Ural Mountains upon *Pinus cembra*. It appeared in widely separated localities through Northern Europe before plant pathology had developed to any extent. That is, organized quarantines, present methods of spraying, and many other methods now used in fighting plant diseases were unknown at that time. The fact that the disease was prevalent practically throughout northern Europe before it became generally known, showed plainly that it was firmly established throughout that region. This meant that

⁵⁷ Posey, G. B., and Gravatt, G. F. Op. cit.

eradication was impossible. Local control has therefore been the only aim of the Europeans. Besides all this, the application of methods of control to plant diseases in Europe has never been developed to such a point as it has in North America except for relatively few diseases of the more important cultivated crops. There has apparently never been a well-planned investigation of the control of this disease extending over a number of years anywhere in Europe. All European publications upon control are fragmentary. It is evident that many scattered efforts have been made to control the disease there, but the results have never been published.

As stated above, the status of *Pinus strobus* in Europe is entirely different from its status in North America. While it has been more than 200 years since it was introduced into Europe (5), it of course has not approached the distribution that a tree does in its native region. It has been widely distributed in Europe as a park and ornamental tree and has been very popular for this purpose. As a forest tree it is a species which is planted in relatively small blocks and even then only on an experimental scale. In Europe it is essentially an ornamental tree rather than an important timber tree. Its total value there is exceedingly small compared to its total value in North America.

Legislation against plant diseases in Europe is so complicated that no attempt will be made here to give an outline of it. Incidentally, it should be stated that Tubeuf (162, 163, 164, 169, 170, 174) has repeatedly called attention to the fact that commercial nurseries have been and are still spreading this disease throughout Germany. In 1904 he (170) repeats earlier demands for a national control of the forest-tree nursery trade and goes so far as to refute the statements of Schwarz (125) that this disease in the nurseries at Halstenbek is absent or negligible. It is evident that the nursery trade dominated the situation and prevented such action.

Since the disease on *Ribes* plants is essentially one of the leaves, there has been an apparent chance for success by spraying them. Tubeuf (165) seems to have been the first to report on such tests. He sprayed *Ribes* leaves in the greenhouse with Bordeaux mixture and then set the sprayed plants among those already diseased. Numerous uredinia soon developed on the lower sides of the sprayed leaves. Jaczewski (58) says that spraying with Bordeaux mixture is not very effective.

Ewert (37) in 1912, to prove whether infection of *Ribes* leaves always occurs on the lower side only, made a test on a bush of *Ribes nigrum*. This bush was one of a number of *Ribes* plants upon which *Cronartium ribicola* had appeared every year for a decade. One-half of the bush was sprayed on the lower sides of the leaves only; the other half was untreated. Spraying was done on March 28, April 9

and 27, May 3, 7, and 20, June 1, and July 9. About 1,000 leaves were borne on the bush on June 27 so that each half had approximately 500 leaves. At that time the unsprayed half had about 250 leaves so heavily infected on the lower surface that some were already about to fall. On the sprayed half only 10 leaves were infected, all but one of these had only 1 or 2 sori, a single leaf had more. In this season the fungus attacked all the *Ribes* bushes very heavily, more so than for 10 years preceding.

It is noted that Ewert does not say specifically that sori formed only on the lower surface of the leaves. They may be presumed to have done so.

On April 26, 1913, Ewert placed four potted plants each of *Ribes nigrum*, *R. aureum*, and *R. rubrum* (var. Red Holland) around a tree of *Pinus strobus* heavily infected with *Cronartium ribicola*. On April 26, May 9, 17, and 24, June 6 and 21, and August 3, the several plants of each species were treated as follows:

Plant 1, sprayed with 1 per cent Bordeaux mixture on only the upper surfaces of the leaves.

Plant 2, sprayed with 1 per cent Bordeaux mixture on only the lower surfaces of the leaves.

Plant 3, sprayed with 1 per cent Bordeaux mixture on both surfaces of the leaves.

Plant 4, untreated check plant.

The checks on May 17 had two leaves with a considerable number of uredinia; on May 25 almost all leaves bore uredinia; and on July 28 there were 50 heavily infected leaves.

Plants numbered 1 (sprayed on the upper surfaces only) on May 25, showed the first uredinia on one leaf; on June 3 six leaves were infected, two very heavily; on July 28 there were 50 infected leaves.

Plants numbered 2 (sprayed on the lower surfaces only) on June 3 first showed very slight infection on two leaves; on July 28 four leaves were infected, all lightly.

Plants numbered 3 (sprayed on both upper and lower surfaces) on July 24 were healthy. On June 28 one leaf bore a single uredinium.

Here again Ewert fails to state definitely whether or not the infections were all on the lower surface of the leaves.

Ewert's experiment of 1912, spraying one-half of a *Ribes nigrum* bush, was repeated in 1913. In this case the sprayed leaves remained healthy, except where they were not thoroughly reached with the spray. This exception seems to the writer to be significant, as it indicates that spraying carefully enough to control the disease was apparently not practicable even for as painstaking an experimenter as Ewert showed himself to be in planning and carrying out these tests. In 1912 the disease was very virulent, while in 1913 it was not. This probably largely explains the better showing made in 1913 in these experiments. Although spraying greatly

reduced the number of uredinia, it did not entirely prevent their formation.

The spraying of pines with fungicides apparently has not received much attention. It is reported that the infection of young seedlings of white pine has been controlled by spraying in Belgium (106).

Pines have been treated in Europe by the application of various chemicals, but the following cases are the only ones where results are given.

Hostermann (55) treated the affected parts of two *Pinus strobus* trees with 10 per cent and 20 per cent solutions of carbolineum. This was applied with a brush on April 28, 1908, before the æcia matured, and again on May 12 and 18. The next spring, æcia started to develop, and the treatment was repeated with a 50 per cent solution of carbolineum. The tree was apparently unhurt, but in the spring of 1910 the fungus was still alive.

In another case (102), where 15-year-old trees were badly attacked on the trunk and the leaves had turned noticeably yellow, the bark was scraped off and the area bandaged with "carbolineum avenarius." A second tree was scraped and a 10 per cent solution of potassium permanganate applied. On a third tree a 1 per cent solution of copper sulphate was used. The first and second trees recovered and the last one died.

Büttner (9) treated 18-year-old *Pinus monticola* trees which had trunk infections. Attempts at cutting out the infections failed. He then applied "tree wax" to the visible infection itself and 20 cm. above and below it. The trees showed no blister rust in 1906. It would be interesting to learn if this held true for several years.

Eriksson (33) recommends the use of tar to cover the infections and prevent the distribution of the spores.

Tubeuf (164) says that valuable trees may be saved by cutting out infections and treating with lysol, asphalt, etc., if *Ribes* are removed for a distance of 50 meters, so that no new infection can occur.

Kneiff (74) removed blisters by frequent wet rubbing. He also used "tree wax" and cloths wet with carbolineum. These hindered the disease, but he says the best way to fight it is the removal and burning of the diseased parts or plants.

Pechon (105) advises burning affected trees and states that treatment with tar and similar substances will not suffice.

Köhler (75) tried cutting out and smearing, but gave up these methods as causing too much injury and even death. He sprayed the trunks with a strong stream of water before the blisters opened in the spring. The blisters disappeared and the trees formed new bark.

Fungi which parasitize *Cronartium ribicola* are not uncommon. Their use in artificial inoculation of infections on pines has been attempted (172, 173, 174), but with little success. There appears to be little prospect for success commensurate with the expense involved.

The separation of the pines from the *Ribes* plants is the most efficient method of controlling the disease in a given locality. To judge from the frequency of this recommendation for combating the disease in European literature, apparently considerable work of this kind has been done in Europe; but no definite statement of results in specific instances have been found.

The use of screens of another species of tree between *Ribes* and *Pinus strobus* has been recommended in Europe (131, p. 41). No one has stated the results of such treatment in any given instance, however.

There must be a chance to secure much valuable data on the success or failure of various methods of treatment which have been tested in Europe, but which have never been published. This can only be done by making definite investigations in Europe from the American standpoint. It must be remembered that from the European point of view the white pine is an introduced and comparatively unimportant tree. Its diseases, therefore, are not made the subject of systematic and prolonged study. Many facts of value fundamental to the control of this disease in America can only be determined by the intimate study on the ground of the much older infections of Europe.

Experiments in Control in North America.

In all control of parasitic plant diseases the fundamental thing is to determine the extent and the distribution of the disease to be controlled. The parasitic fungi are so generally distributed by the wind and are so insidious in their spread that they usually have gotten well started before their presence is discovered. Newly discovered imported diseases must be attacked at once or not at all, if eradication is to be accomplished, but more attention should be given to the matter of determining reliably the extent of outbreaks of such diseases. Scouting is a very important part of any disease eradication or control campaign. A well-conducted, intensive, plant-disease survey will do much to aid in determining the status of a new disease.

METHODS USED.

The control of white-pine blister rust has been attempted in North America (1) by means of quarantines of the host plants, (2) by the eradication of advance infections, (3) by the separation of the two hosts, (4) by sanitation, (5) by screening *Ribes* or pines

with other species, (6) by the judicious selection of planting sites for pines, and (7) by such minor methods as spraying, close pasturing of *Ribes*, and the removal of the diseased plants or parts of them.

QUARANTINE.

In North America (131, p. 54-55), Canada took the first official action against the white-pine blister rust, placing it on her list of proscribed plant diseases and later prohibiting the entry of all 5-leaved pines from all other countries.

Since then (2) a quarantine has been declared against the shipment of *Ribes* from points east of a line between Saskatchewan and Alberta to points west of that line. The shipment of *Ribes* to points west of this line is allowed from points in the United States south of the above protected area. These modifications are made to help protect the western white-pine area from the shipment of this disease in nursery stock, and to connect with the Mississippi Valley quarantine line in the United States, which has been established

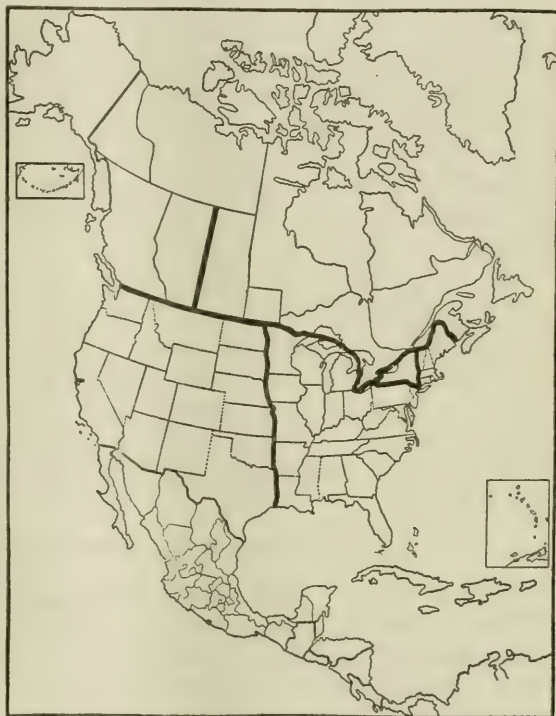


FIG. 13.—Outline map of North America, showing the quarantine lines established by the United States Department of Agriculture to control the white-pine blister rust by prohibiting the shipment of the host plants from infected territory to uninfected sections. The quarantine line established by Canada to prevent the shipment of diseased nursery stock across the prairie region from the eastern Provinces is also shown.

with this end in view (fig. 13). The United States Government in 1912 (94) put in force a regulatory act controlling the entry and movement of nursery stock. This act prohibits the entry of 5-leaved pines and of *Ribes* from Europe, Asia, and Canada; forbids the shipment of such stock from the eastern section of the country to points west of the western boundaries of the States of Minnesota, Iowa, Missouri, Arkansas, and Louisiana; and also forbids the

shipment of 5-leaved pines and of *Ribes nigrum* from the States of New England to any of the other States and from New York to points outside that State. Still more recently, an absolute embargo has been placed on ornamental and forest tree and shrub stock from other countries (fig. 13).

These quarantines prevent our getting more of the white-pine blister rust from other countries. The Great Plains region forms a natural barrier (fig. 13) against the spread of this disease from the East to the West (97, 98, 141, p. 7; 148)). Since it is already well distributed and established east of this barrier, the immensely valuable western white pines can be protected very efficiently by preventing the shipment of white pines and *Ribes* from the infected section to the western region, which is still free from the disease. This is accomplished by quarantine, which is designed to prevent the shipment of infected stock from a generally infected district to those States which are not generally infected and to exclude plant pests from all the rest of the world (98).

Within the past four years many of the various States have enforced regulatory measures with reference to this disease (94). These States are California, Delaware, Georgia, Idaho, Illinois, Indiana, Kansas, Maine, Maryland, Massachusetts, Michigan, Minnesota, Montana, Nevada, New Hampshire, New Jersey, New York, North Carolina, Oregon, Pennsylvania, Rhode Island, South Carolina, South Dakota, Tennessee, Vermont, Washington, West Virginia, and Wisconsin.

ERADICATION OF ADVANCE INFECTIONS.

In 1909, when *Cronartium ribicola* was first found upon white pines in North America, it appeared to occur only on recent shipments of young trees from Europe. That is, it was present in advance infections, and so far as could be determined there was no generally infected area. Since that time areas have been found which are generally infected, and we have both types of infections to reckon with. (See figs. 2 to 12.) Where advance infections were small it appeared to be feasible to attempt eradication of the disease, but when generally infected areas were found eradication became impossible, and local control was the only feasible thing to be attempted.

When this disease was first discovered on *Ribes* in 1906 at the Agricultural Experiment Station at Geneva, N. Y., an attempt was very properly made to eradicate the disease. All of the *Ribes* in the infected plat were destroyed. Very few white pines were within half a mile, and none of these were found diseased. Stewart (150) published an excellent account of this case. It was not then known that the æciospores readily blow for miles in a viable condition, nor was that fact established until rather recently (128, 145, 146).

In 1909 it was learned that great quantities of infected young white pines had been imported from Europe in 1907, 1908, and 1909. (Fig. 1.) With conditions as they appeared to be, it was believed that eradication might be possible, and this was attempted. The disease was held in check in such shipments of diseased trees as could be located. But many could not be located. Moreover, for years before, as was subsequently learned, nurserymen and private individuals had imported from Europe many infected white pines. These we had no means of knowing about until too late, since the importers and planters did not inform us concerning them, even after the publication of warnings against the disease. Such diseased importations have been the centers from which most of our large outbreaks have started. So far as we can learn no Federal agency has imported white pines upon which this disease has been found.

More complete knowledge of the life history of the fungus has shown that it is impossible to eradicate it where both *Ribes* and white pines are native and abundant, after the æciospores are once set free in quantity. If both pines and *Ribes* be removed from a given area the disease may be eradicated in that area but it will have escaped beyond that area by means of the æciospores. This happened in Minnesota and Wisconsin, where all the white pines and *Ribes* were removed from large infected areas.

The removal of pines has been accomplished in a few cases. Entire plantings of imported pine stock were destroyed soon after they were found to be diseased, and in these cases *Ribes* were also removed or were absent from the area treated. The forestry officials of the State of New York took the lead in this work, destroying 1,200,000 imported trees in their nurseries in 1910 and 1911. A number of plantations were also destroyed in New York, New Jersey, and Vermont (131, 139). As early as 1912, the total destruction of diseased lots of imported white pines (133) was urged rather than weeding out only those which were visibly diseased. Public opinion would not permit this to be done in the wholesale manner that was necessary for efficiency. Yet this was the one efficient manner of handling such imported trees (136) before generally infected areas had developed.

SEPARATION OF THE TWO HOSTS.

The fact that each form of spore will infect but one of the hosts, at once indicates that a separation of these hosts will prevent the further progress of the parasite within the control area. If the pines only are removed, the disease will be likely to die out on the *Ribes*, since it apparently overwinters on them only infrequently; if the *Ribes* are removed, the disease is isolated on that particular lot of pines, where it overwinters (if the diseased trees are not also found and removed) and produces new crops of æciospores each spring. The

disease is kept from attacking more pines within the area where the Ribes are removed, but it may spread to Ribes miles away, there to start new pine infections, each of which will act as a new center of infection in future years. This makes it practically impossible where both white pines and Ribes are native entirely to eradicate the disease after the aëciospores are once set free.

REMOVAL OF PINES.

In all work where pines have been removed the Ribes have been absent or were also removed; hence, all this work is placed under "Eradication of advance infections." In some of the States, Ribes-growing sections are being established, and it is expected that white pines will be entirely removed from such areas.

REMOVAL OF RIBES.

Experiments on a large scale are in progress in all of the States of New England and in New York, Wisconsin, and Minnesota for the removal of all Ribes in certain areas, to determine whether it is practicable thus to protect valuable white-pine stands.

Much work of this sort has been carried on during the past four years. Infected areas have been chosen and the Ribes removed under various conditions to show what possibilities there are in such work (23, 24, 25, 103, 104). The removal of all Ribes plants in a given area is a difficult matter. Wild Ribes offer the greatest difficulties. It is not humanly possible to find every plant in wild woodland; plants pulled up, if left touching the soil, may again take root and persist in a living condition; pieces of root crown and occasional pieces of roots left in the soil sprout and make new plants (23, p. 8); fruits on the pulled bushes fall off and start a crop of seedlings to replace the parent plant; seeds of old fruits already on the ground may germinate and start seedlings. Nevertheless, the results of this work are encouraging. Wild currants and gooseberries do not reproduce rapidly in an area that has been worked by an efficient crew. Thorough checking on 2,485 acres in 8 separate tracts previously gone over by eradication crews showed that on an average acre, 62 bushes (95.5 per cent) were destroyed in the first working and 3 bushes in the second working. Of the latter, two bushes were missed in the first working and one bush developed from seeds or sprouts. The remaining plants are so small that they carry but 1 to 2 per cent of the total Ribes leafage (24). Moreover, they are usually so low or so covered with other vegetation that very few become infected, so that the work results in almost perfect control of the disease. To judge from data at hand, control areas usually should be reworked within 10 years after the first working (25).

Two principal methods of removing Ribes have been developed. Where Ribes are abundant the Ribes eradication crew has to cover

all the ground and pull the *Ribes* as they go. Where *Ribes* are relatively scarce they are likely to occur only in certain favorable locations. In such territory an expert scout covers the ground, mapping it and indicating the *Ribes* areas to be worked by the crew. In favorable localities this has proved successful and greatly reduces the cost of *Ribes* eradication (25). Experiments in the killing of thick stands of wild *Ribes* with chemicals indicate that this method (113) materially reduces the cost.

Ribes eradication was started as early as 1909, but at that time was limited to plantations of infected imported white pines and to a safety belt of 100 yards around them. In 1910, the width of the safety belt was increased in some of the States to 500 feet, and in 1915 in Massachusetts to 500 yards. In 1916, 600 yards was taken as the safe width for all situations. Prior to 1919, facts concerning the spread of *Cronartium ribicola* from *Ribes* to pines were not definitely known. As a result of the investigations of the germination and dissemination of the sporidia the width of the *Ribes*-free zone was set, in 1919, at 200 to 300 yards for average conditions (25, 146).

In 1917, when extensive areas were first cleared of all *Ribes*, lack of experience in such work by all connected with the work greatly reduced its efficiency, but even then it was found that the outlook was not hopeless, although the cost of eradication of *Ribes* was too high to be justified except where pine stands were valuable. Efficiency has been steadily increased since then until it has been found that men green in this work can be quickly taught to find and destroy at least 95 per cent of all wild *Ribes* plants the first time over the ground (24, 25). A system of checking the work has been developed, as well as a system of accounts, so that present results are quite accurately known.

The cost of *Ribes* eradication has been steadily reduced. In 1918, 105,977 acres were worked in New England at a labor cost of 44 cents per acre. In New England and New York the average cost per acre including supervision in 1918, was 66 cents. In 1919, in New York and New England, 252,114 acres were worked at an average cost per acre of 54 cents, including supervision, and of 42 cents for actual labor (24, 25). Improved methods are expected to reduce still further this cost as, in New England alone, the cost in 1919 was 24 cents per acre, owing to the use of improved methods (24).

The efficiency of *Ribes* eradication with respect to pine infection will become evident as time elapses. Examination of areas where *Ribes* were eradicated in 1916 and 1917 has shown no new pine infections. This is in spite of the considerable number of *Ribes* missed in the early work.

The experiments in the removal of *Ribes* on an extensive scale have gone far enough to prove that it is a practical method of protecting pine stands. Accordingly the public has been urged to destroy wild and cultivated *Ribes* within at least 200 yards of valuable pine stands in the generally infected regions.

Assistance to individual pine owners, towns, and associations in protecting pine areas from the blister rust is given by the New England States, New York, Wisconsin, and Minnesota, in cooperation with the United States Department of Agriculture. In 1919, about \$10,000 was subscribed for cooperative eradication of currants and gooseberries by individuals and associations in New York. In Massachusetts, local cooperators furnished \$1,075. In New Hampshire, 53 towns voted appropriations totaling \$8,514, and 34 individuals and firms subscribed \$2,053 additional. The interest of the public in blister-rust control is further evidenced by the fact that this State destroyed 21,171 bushes of cultivated currants and gooseberries belonging to 1,023 owners, and only 3 owners insisted on compensation for their bushes (24).

The State and Federal authorities favor cooperation with towns, counties, associations, or groups of individuals in order to free from *Ribes* as large an area as possible in each locality. This reduces cost per acre and increases the effectiveness of the protection to pines.

SCREENING RIBES AND PINES WITH OTHER SPECIES.

Screens of heavy underbrush or trees surrounding or covering *Ribes* will do much to prevent infection of the *Ribes* by æciospores and will greatly reduce infection of white pines, if the *Ribes* do become infected (145, 146).

Screens or windbreaks of other kinds of trees around the edge of white-pine stands will greatly reduce infection on the pines. In the same way, planting in mixture or in strips alternating with another species should help to keep the disease down.

SELECTION OF SITES FOR PINES.

Infection by *Cronartium ribicola* may be reduced to a minimum in a generally infected area by judiciously choosing a site for the planting or natural seeding of white pines. Areas where there is a minimum number of *Ribes*, or where they have been eradicated, which are not in moist locations and are not especially subject to fogs or mists, and which are protected by forests or conformations of the land from heavy sweeping winds, are favorable for the encouragement of the growth of white pines. The converse conditions are to be avoided as far as possible.

SPRAYING.

Spraying has been little used in North America to control the white-pine blister rust, as the chances for success have appeared to be slight. Spraying of *Ribes* to prevent their infection has been tested in a number of instances.

In 1915, McCubbin (86) carried on some careful spraying tests with *Ribes nigrum* plants, using both Bordeaux mixture and soluble sul-

phur in parallel experiments. The following statement has reference to spraying that was done every two weeks through the summer:

It was realized that the spray would have to be applied to the under sides of the leaves to be effective, and though this was done as thoroughly as possible in our work, it must be admitted that it takes so much time and care that satisfactory spraying of this kind would be out of the question in a commercial way. Owing to frequent rains during the summer, the best results were not obtained from this work, but even allowing for this it was certain that, though the rust can be greatly reduced by spraying, it can not be controlled sufficiently to prevent the spread of infection. Consequently, whatever value spraying methods may have as a means of protecting individual plantations, they are likely to be of little use in combating the disease as a national pest. In this connection, it has been suggested by the Dominion Botanist that since spraying will not completely control the rust, it may work a positive harm by keeping the infected leaves longer on the bushes in the fall, and thus materially extend the period during which infection of the pine may take place, providing, of course, that the infection of pines is possible throughout the whole season.

Stoddard, in 1918 (23), carried out a spraying test in Connecticut, with the following results:

Spraying experiments for the control of the blister rust were conducted on red and black currants. Results were nearly negative on red currants because of lack of infection. On black currants spraying gave nearly complete control throughout the season. However, such careful and frequent spraying had to be done that it is not considered to be a practical method of control.

No experiments have been made in the spraying of pines, as it has appeared useless in larger trees where the infections have occurred. Seedlings in seed beds of nurseries may perhaps be protected from infection by spraying, as has been suggested by Clinton and McCormick (14). It should be well tested under extreme conditions (106).

CLOSE PASTURING OF RIBES.

The use of animals to feed on the leaves of *Ribes* is feasible if the area is pastured heavily until well cleaned up. Sheep are very close feeders and undoubtedly can be thus utilized (23, p. 7). Goats are the most promising animals for the purpose, however, as they are omnivorous feeders. This method can be recommended only for areas where small pines are absent or too few to be of value.

REMOVAL OF DISEASED PARTS AND DISEASED PLANTS OF RIBES.

The removal of the infected leaves has been attempted in a few lots of *Ribes nigrum* in nurseries, but it is costly and merely palliative in that it is usually only postponing more drastic measures. The cutting back of infected *Ribes* bushes has been tested in a few instances, but like the plucking of the leaves, it is usually unsatisfactory, since the bush remains to take infection another season.

The removal of diseased plants only of *Ribes* is unsatisfactory, as it has been found that it requires repeated visits through the season for the removal of plants which have developed the disease since

previous inspections. This makes the cost of the work prohibitive, and the disease progresses in spite of it.

REMOVAL OF DISEASED PARTS AND DISEASED PLANTS OF PINES.

The removal of diseased parts of infected pines does not appear to be an economical procedure from the viewpoint of the lumberman or wood-lot owner, because of the low value of single trees. For highly valued ornamental trees it becomes possible financially. Under such conditions, the removal of all *Ribes* to prevent new infection, accompanied by careful cutting out of all infections in the pines for several years, will finally result in the elimination of the disease from those trees. Martin, Gravatt, and Posey⁵⁸ have investigated the possibilities of this type of work. They conclude that—

Experimental and practical results show that ornamental pines which have already become diseased can be saved by cutting out the infected parts if treatment is applied in time. The work is easily performed at a comparatively low cost. Treatment can be given any time during the year, but best results will be obtained from April to June when the cankers are more easily found because of the bright orange-yellow blisters. Successful treatment depends primarily upon ability to find the cankers and determine accurately the edge of the diseased area. The workmen should be thoroughly familiar with the symptoms and appearance of the disease on pines.

Where the *Ribes* can not be thus eradicated, other species of trees should be planted to take the place of the white pines. Cutting out infections depends, for success, on finding all of them. The workman must be familiar with the blister rust and be thorough or the results will not justify the cost. If a tree is nearly girdled near the ground, or if most of the branches must be removed, it is useless to attempt to save it. The cutting out must be repeated for several years after all the *Ribes* are eradicated, as dormant and slightly developed infections become visible. Cutting out experiments showed that cutting back for $1\frac{1}{2}$ inches or more from the extreme edge of the infected area insured removal of all diseased bark and stopped the disease in those areas. In practice this distance should be increased to 5 or 6 inches to insure thorough work.

On a main trunk an infection which has extended only part way around the trunk may be treated by peeling off the bark on the canker and to the required distance around it. In this case the safety zone should extend for 4 or 5 inches directly above and below the diseased area but need not extend more than half as far sidewise.

The removal of only diseased white pines in infected imported trees has been inefficient and costly, even where the *Ribes* were removed too. Records of such work in about 900,000 imported trees (136) shows that it is inefficient, although the disease has been checked somewhat. The cost has been great enough to have replaced the imported trees with healthy home-grown ones.

⁵⁸ Martin, J. F., Gravatt, G. F., and Posey, G. B. Treatment of ornamental white pines infected with blister rust. U. S. Dept. Agr. Cir. 177, 20 p., 12 fig. 1921. Seen in manuscript.

In a region where *Ribes* are rare or practically absent the removal of the diseased pines only may serve to prevent progress of the disease. This allows the dispersal of æciospores and may result in scattering infection on *Ribes* miles away. In such cases it will take a long time to detect the escape of the fungus. In areas free from the *Ribes* the aim should be eradication rather than control of the disease, as such areas are the very ones where white pines should be grown in the future.

In generally infected districts where *Ribes* are removed for some distance, it may pay to cut out the worst infected trees to reduce the crop of æciospores and thus reduce infection around the borders of the treated area.

Status of the Control of White-Pine Blister Rust.

The present status of the control of the white-pine blister rust in North America may be summed up as follows:

Eradication of *Cronartium ribicola* is impossible except in small, isolated, advance infections. It should be attempted only in localities where the disease is quite limited in distribution and well separated from the known generally infected areas shown in figure 2. As a national problem, control is the only feasible thing. Protection of uninfected or sparsely infected areas by enforcement of the present Federal quarantines is necessary, since this disease is distributed to great distances only by means of infected nursery stock. The western forests of white pines can be protected from the blister rust for an indefinite period by rigid enforcement of the Mississippi Valley quarantine. A single diseased shipment may undo all attempts to restrict it to the eastern forests.

In the eastern forests blister-rust infection on *Pinus strobus* is rapidly developing. A strip survey in one locality in New Hampshire (24) shows that one-fourth of the white pines on an area of 72 square miles are now infected. The areas marked as generally infected in figure 2 show the great increase in general pine infection. Much of this infection will become visible in the next three years. It is an insidious disease, a tree not being noticed as diseased until it is heavily infected. There is abundant evidence that it is destructive to merchantable trees as well as to younger ones. It is just getting under headway.

Ribes nigrum is far the most dangerous species, but all *Ribes* are dangerous to white pines in generally infected areas. In such areas the disease can be controlled by the removal of all *Ribes*. Local control depends on the removal of *Ribes* within white-pine areas and the education of the white-pine owners to remove *Ribes* as a routine part of white-pine forest management. Local control by the removal of *Ribes* can be taken up at any time in the future, but if the present stand of trees is to be saved action must be taken at once.

A few years delay will mean serious loss. It is a simple and practical precaution to destroy the currant and gooseberry bushes before they destroy the pines. The demonstrated effectiveness of this method of control justifies pine owners in uprooting currant and gooseberry bushes on a large scale (24).

Those who do not do this in their pine lands and for a distance of 200 to 300 yards outside will be likely to see a valuable asset turned into a liability. In areas where the white pine is an important tree cultivated *Ribes* should not be planted. A number of States already have laws prohibiting such planting without permission from the State authorities except in areas designated and set apart as "currant-growing districts."

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DEVELOPMENT OF TUBERS IN THE POTATO.

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SCOPE OF THE EXPERIMENTS.

The conditions which attend the setting and subsequent development of the tubers of the potato (*Solanum tuberosum* L.) are of interest not only to the plant physiologist but also to the practical grower, as a knowledge of the relation of these factors to crop production may, to a certain extent, be put to practical use.

The experiments described in the following pages were conducted at the Colorado Potato Experiment Station, Greeley, Colo., during the seasons of 1916, 1917, and 1918. A few minor observations were also made in Maine in 1919 for the purpose of verifying the conclusions previously reached relating to the time of the beginning of tuber formation.

While these studies could profitably be extended to cover a longer period and include a greater number of varieties and a wider range of environmental conditions, it is deemed advisable to place on record the results obtained up to the present time, since these lines of investigation have been temporarily suspended.

WORK OF PREVIOUS INVESTIGATORS.

While very extensive studies of the potato plant have been made, the development of tubers has received comparatively little attention. Jones and Orton (5, p. 155-156)¹ report results obtained

¹ The serial numbers in parentheses refer to "Literature cited" at the end of this bulletin.

with the White Star variety in 1893, harvested at 10-day periods from August 2 to September 22, and with the White Star and Delaware varieties in 1898, harvested at the same intervals from August 4 to October 6. There was found to be an increase in yield up to the time of the last harvest. A considerable part of the yield of tubers of marketable size developed after the 1st of September.

Kohler (7, p. 109-111), in experiments with the Early Ohio variety in 1909, by digging tubers at 7-day intervals from July 31 to August

30 obtained an increase in weight at the rate of 7.18 bushels per acre each day. The gain was also found to be very uniform throughout the period, with the exception of a slight drop at its end, which was attributed to the loss of foliage as the result of disease.

Werner (11, p. 20-21) in 1917 found that tubers of the Green Mountain variety harvested August 10, 20, 30, and September 8 and 11 showed daily increases of 2.34 bushels per acre during the first 10-day interval, while the increases for the last 3-day period were at the rate of 5.27 bushels.

Wilfarth, Römer, and Wimmer (12)



FIG. 1.—Plant of the Irish Cobbler variety of potato, showing the tubers borne on short stolons.

found, in both field and pot experiments with the Geheimrat Theil variety, a fairly constant rate of increase in the weight of tubers during the four periods of growth which were studied. Analyses showed comparatively small changes in the percentages of the mineral constituents throughout the season, though there was a slight trend toward a decrease until the fourth period, when a very small increase was indicated.

Experiments conducted in boxes with the Up-to-Date variety, by Ramsay and Robertson (9), where four harvests were made at inter-

vals of approximately one month each, beginning one month after germination, showed that tuber development continued during the entire period, though the rate of increase was diminished during the fourth month. Analyses of the tubers harvested at the end of each monthly period showed that with respect to the mineral constituents there was little change in composition after the first month. Those produced during the first period, however, contained slightly higher percentages of these constituents than were found in the later harvests.

Chemical studies by Jones and White (4) with the Delaware and White Star varieties, dug at intervals of 10 days from August 4 to November 3, 1898, and from August 12 to October 11, 1899, showed that the most important changes occurring during the period of the experiment were those of yield rather than composition. There was, however, a very small decrease in the percentage of dry matter and nitrogen-free extract and a slight trend toward an increase in the protein, ash, and crude fiber as the crop approached maturity.

Studies of the composition of tubers before and after growth had ceased led Prunet (8) to conclude that during the period of growth the nutritive substances are uniformly distributed throughout the tuber, but after full size has been reached there is a movement of these substances toward the vicinity of the apical buds.

Data regarding the growth of tubers after frost were obtained by Follstad (1), who weighed one tuber from each of four hills on September 13, 16, 20, and 27, weighing the same tubers on each of the different dates without detaching them from the stolons. The leaves had previously been killed by frost on September 10. The

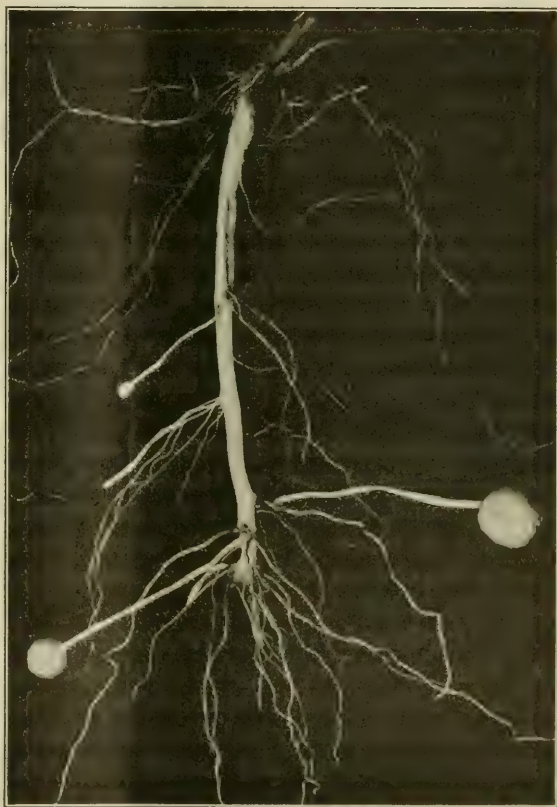


FIG. 2.—Plant of the Charles Downing variety of potato, showing the relatively long stolons on which the tubers are borne.

results showed an average gain in weight after the death of the foliage of 26.4 per cent, or 57 bushels per acre.

DESCRIPTION OF THE TUBER-BEARING PARTS.

The tubers are borne on underground stems, commonly called stolons, which are modified branches arising from the nodes of the main stem and situated below ground. The development of the buds into stolons rather than leaf-bearing branches depends largely upon certain definite environmental conditions, chief among which is the exclusion of light. De Vries (10) maintains that each axillary bud of the stem of a potato plant has the capability of developing, according to the conditions which surround it, into either a leafy stem or a tuber-bearing stolon. This is further substantiated by Franz (2), who states that if the lower buds are exposed to the light green shoots will generally develop instead of stolons, likewise the upper axillary buds will develop into stolons instead of green shoots if light is excluded early enough.

The arrangement of stolons on the stalk is in general five ranked, though there are many exceptions to this, which are attributed to the failure of some nodes to develop. This same arrangement occurs with the leaf scales on the stolons. The stolons terminate with leaf scales which are strongly recurved, usually at an angle between 90° and 180° . No law has been observed by the writer governing the direction of the recurving.

The stolons start comparatively early in the growth of the plant, usually within a week or ten days after the plants have appeared above ground, the stolons of the early varieties appearing a little in advance of those of the late ones. Under normal conditions of growth the stolons should be well started by the time the plants have reached a height of 4 inches.

The length of the stolons is subject to great variations, ranging from less than an inch to lengths equaling or occasionally exceeding 18 inches. While there is much variation within the variety, and, in fact, in the individual plant, there is a fairly well-defined relationship between stolon length and variety, e. g., the Early Ohio is characterized by very short stolons, while, on the other hand, varieties are occasionally found in which the stolons extend over such a wide area as greatly to increase the work of digging. (Figs. 1 and 2.)

DETAILS OF THE EXPERIMENTS.

EXPERIMENTAL METHODS.

The material used for the experimental work was grown under field conditions, the cultural practices employed following those in general use in the locality in which the work was done. The digging operations were performed by hand, special care being taken to get

all the tubers in each hill. The minimum size of tuber saved was one-half inch. Where a separation was made into marketable potatoes and culls the division was by weight, the marketable tubers including those equaling or exceeding 3 ounces (above 85 grams), and the culls, those below this limit.

THE FORMATION OF TUBERS.

Tuber formation begins, in general, at about the end of the period of flower-bud development, though this is not in all cases an exact criterion. In the early varieties the tubers invariably start to form by the time the buds are fully developed, while in the late varieties evidences of tuber formation may not be found until the buds have started to open. The Green Mountain variety appears to be exceptionally late in this respect, observations having shown that, in Maine at least, the formation of tubers did not start until considerable bloom was in evidence.

The first indications of tuber formation are seen in the swelling of certain localized portions of the stolons. With very few exceptions these enlargements occur only at the ends



FIG. 3.—Ends of stolons of the Pearl variety of potato, showing different stages in the beginning of tuber formation. Left, stolon before tuber formation has started; center, swelling of the end of the stolon, which is the first stage in the formation of the young tuber; right, a later stage, showing the globular-shaped tuber.

of the stolons or, if the stolons are branched, at the ends of the branches. At first the swelling assumes a clavate shape but soon becomes globular, and as further development takes place the growing tuber assumes the characteristic shape of the variety. (Figs. 3 to 6.) According to Jurgens (6) the form of the tuber is governed by the relation of the length growth to the thickness growth.

Statistical studies.—To determine the rate of growth of the tubers, 200 hills of the Rural New Yorker variety were dug at 1-week intervals in 1916 and 1917, beginning soon after tuber formation had started and continuing until after the vines had been completely killed by frost. The records of the weight and number of tubers were obtained for each hill. In 1917 additional data were obtained from the same material by putting together all the tubers after the weighing of the

individual hills had been completed and dividing the population into 25-gram classes.² The results are shown in Tables I, II, and III.

TABLE I.—*Rate of development of potato tubers at Greeley, Colo., in 1916 and 1917.*

[Data from 200 hills of the Rural New Yorker variety dug at 1-week intervals during each season.]

Date of digging.	Time after planting (days).	Number of tubers.		Marketable tubers (per cent).		Weight (grams).					
						Average.		Largest—		Increase per hill.	
		Total.	Average per hill.	Num-ber.	Weight.	Total.	Per tuber.	Per hill.	Tuber.		Hill.
Season of 1916:											
Aug. 24.....	72	1,085	5.4	2.4	7.1	37,235	34.3	186.2	160	418	.....
Aug. 31.....	79	1,151	5.8	34.8	61.2	79,028	68.7	395.1	299	856	208.9
Sept. 7.....	86	1,220	6.1	49.6	80.1	114,351	93.7	571.8	417	1,135	176.7
Sept. 14.....	93	1,169	5.8	65.3	91.7	150,987	129.2	754.9	715	1,449	183.1
Sept. 21.....	100	1,295	6.5	66.4	91.7	179,480	138.6	897.4	631	1,861	142.5
Sept. 28.....	107	1,125	5.6	71.4	94.1	193,637	172.1	968.2	852	1,826	70.8
Oct. 5.....	114	1,048	5.2	75.5	95.4	197,123	188.1	985.6	833	2,079	17.4
Season of 1917:											
Aug. 16.....	64	863	4.32	0	0	10,843	12.6	54.2	55	142	.....
Aug. 23.....	71	870	4.35	5.2	14.7	31,579	36.3	157.9	180	366	103.7
Aug. 30.....	78	922	4.61	33.2	60.2	65,064	70.6	325.3	255	670	167.4
Sept. 6.....	85	957	4.79	59.9	87.0	107,746	112.6	538.7	409	1,105	213.4
Sept. 13.....	92	960	4.80	70.0	95.7	142,470	148.4	712.4	735	1,480	173.7
Sept. 20.....	99	987	4.94	69.1	96.2	162,745	164.9	813.7	582	1,745	101.3
Sept. 27.....	106	928	4.64	73.5	97.3	186,460	200.9	932.3	815	2,270	118.6
Oct. 4.....	113	984	4.92	74.1	97.0	218,035	221.6	1,090.2	903	2,100	157.9
Oct. 11.....	120	935	4.68	79.4	97.6	222,055	237.5	1,110.3	991	2,280	20.1
Oct. 18.....	127	931	4.66	79.7	97.7	228,755	245.7	1,143.8	875	2,020	33.5

A study of the data presented in Table I brings out many points of interest. It will be seen that practically the entire crop of tubers was set at the beginning of the period of tuber development, probably within the space of a very few days. The data, however, show a slight increase in the number of tubers up to and including the third digging, in September; also a decrease after that period, so that the numbers at the beginning and at the end of the sampling period are very nearly the same. A possible explanation of this fluctuation is that the numbers employed may not have been large enough to eliminate the so-called experimental error. On the other hand, it seems quite probable that the small increases indicated in the records as occurring early in the season were actual. Toward the end of both seasons it was observed while digging the hills for the statistical studies that some of the very small tubers slightly below half an inch in diameter had shrunk considerably, and occasional evidences of the almost complete disintegration of these small sizes were found. If this condition occurred in tubers originally above the half-inch size, which would have been saved and counted at the earlier dates of sampling, it would account for the apparent decrease in the number of tubers toward the end of the season. Further studies are needed to determine whether this is the cause.

In both years there was an increase in the weight per hill and in the average weight per tuber throughout the entire period of the

² Twenty-five grams are about equivalent to 0.88 ounce avoirdupois.

investigation. In 1916 the percentage of marketable tubers with respect to both number and weight increased up to the end of the season, while in 1917 the number percentage remained nearly constant after October 11 and the weight percentage after September 27.



FIG. 4.—Young plant of the Irish Cobbler variety of potato, showing its root system and the starting of stolons. The plants shown in figures 4 to 6 were grown by and photographed under the direction of W. V. Shear.

The rate of growth was found to be very rapid during the early part of the period of tuber development. The largest increases per week (208.9 and 213.4 grams in 1916 and 1917, respectively) were at the rate of approximately 30 grams (1 ounce) per hill for each day.



FIG. 5.—Plant of the Irish Cobbler variety of potato just after tuber formation had started.



FIG. 6.—Plant of the Irish Cobbler variety of potato, showing later stage of tuber development.
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These maximum rates were reached during the week ended August 31 in 1916 and September 6 in 1917, or after a growth period, from the time of planting, of 79 and 85 days, respectively. After these dates the gain per week gradually decreased. Since the first week in September marked the termination of irrigation in both seasons, it is probable that the falling off in the rate of increase in weight per hill at such a comparatively early stage of the period of tuber development was due, in part at least, to the diminution of the moisture supply. There was no evidence of maturity of the plants at this time, the Rural New Yorker being a late variety which in this locality remains green and vigorous until killed by frost. In 1917 light frosts on the nights of October 7 and 8 killed the leaves of the plants on the experimental plats and a severe frost on October 11 completely killed the vines. The vines were also killed after the next to the last digging in 1916, so that the last increase recorded in each season represents the extent of tuber growth that had taken place after the death of the vines.

An inspection of Table II shows that there was a gradual spreading out of the frequency distributions toward the high values as the season advanced until the digging of October 4, after which no important changes occurred. One of the most striking features brought out in this table is the ununiform rate of growth in the tuber population. The last two samples of the season showed that between 11 and 12 per cent, or nearly one-eighth of the entire number of tubers, had failed to grow beyond the 25-gram class, the average weight of those remaining in this class being 8.2 grams. On the other hand, the data taken at each digging period show a rapid increase in the growth of the tubers of the larger sizes up to the time of the last harvest in September. These inequalities in growth are brought out more clearly in figure 7. It has previously been shown that practically all the tubers which grow to more than one-half inch in size set early in the season, probably at very nearly the same time; therefore, we must conclude that those which are small at the end of the season are of this relative size because of their failure to grow at a normal rate and not because they are of much more recent origin than the larger sizes.

In Table III, which gives the weight of the tubers in each of the 25-gram classes, the increases in size from week to week are shown by the gradual extension of the distribution and a shifting of the mode toward the higher classes up to October 4, after which there was little change. The failure of part of the small tubers to grow sufficiently to exceed in weight the limits of the 25-gram class, previously referred to, is further emphasized by this table, which shows very little change in the total weight of tubers in this class after September 20. The changes in the distribution with respect to weight resulting from tuber growth are shown in figure 8.

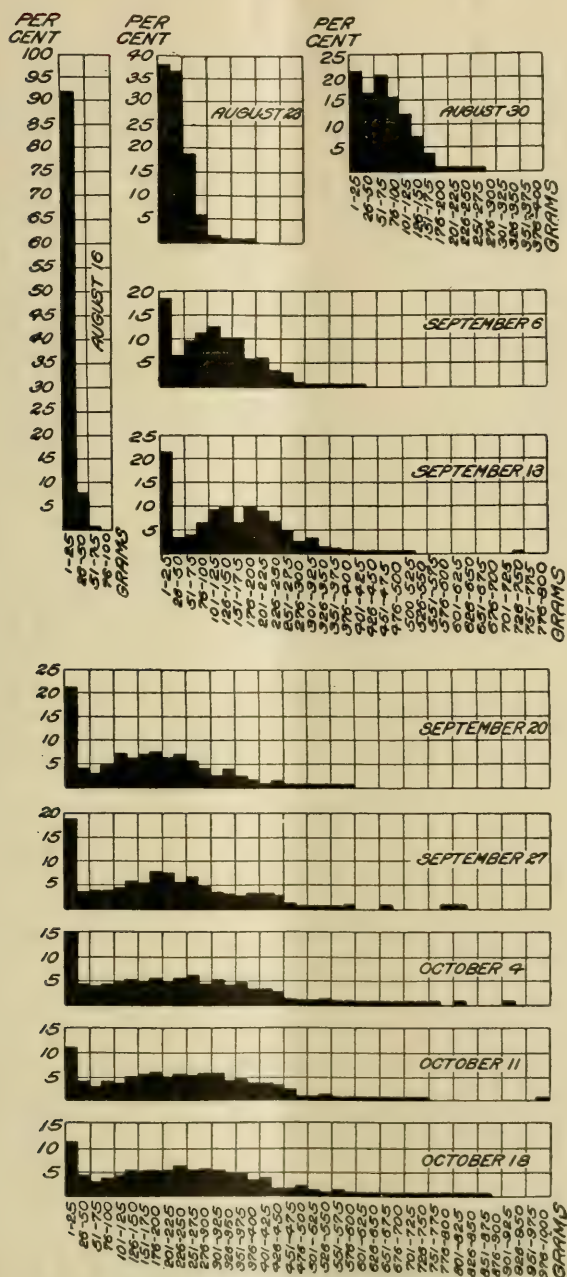


FIG. 7.—Diagram showing the percentage of tubers by number in classes, differing by 25 grams in weight, found in the tuber population of 200 hills at each date of digging.

TABLE II.—*Number and its percentage of Rural New Yorker potato tubers in each of the 25-gram classes, showing the changes in the distribution of the tuber population as the season advanced after planting on June 13, 1917, at Greeley, Colo.*

Weight limits.	Aug. 16.		Aug. 23.		Aug. 30.		Sept. 6.		Sept. 13.		Sept. 20.		Sept. 27.		Oct. 4.		Oct. 11.		Oct. 18.	
	Num- ber.	Per cent.	Num- ber.	Per cent.	Num- ber.	Per cent.	Num- ber.	Per cent.	Num- ber.	Per cent.	Num- ber.	Per cent.	Num- ber.	Per cent.	Num- ber.	Per cent.	Num- ber.	Per cent.	Num- ber.	Per cent.
Class No. 1, 1 to 25 grams.	793	91.89	329	37.82	197	21.37	177	18.50	204	21.25	216	21.88	174	18.75	155	15.75	110	11.76	108	11.60
Class No. 2, 26 to 50 grams.	68	7.88	314	36.09	153	16.59	62	6.48	28	2.92	42	4.26	26	2.80	42	4.27	39	4.17	39	4.19
Class No. 3, 51 to 75 grams.	2	.23	161	18.51	188	20.39	91	9.51	33	3.44	31	3.14	35	3.77	41	4.17	27	2.89	27	2.90
Class No. 4, 76 to 100 grams.			46	5.29	143	15.51	108	11.29	62	6.46	48	4.86	35	3.77	42	4.27	40	4.28	37	3.98
Class No. 5, 101 to 125 grams.			17	1.95	115	12.47	120	12.54	87	9.06	71	7.19	37	3.99	43	4.37	37	3.96	40	4.30
Class No. 6, 126 to 150 grams.			1	.11	68	7.38	99	10.34	93	9.69	62	6.28	50	5.39	51	5.18	49	5.24	53	5.69
Class No. 7, 151 to 175 grams.			1	.11	30	3.25	98	10.24	64	6.67	72	7.29	47	5.06	47	4.78	52	5.56	43	4.62
Class No. 8, 176 to 200 grams.			1	.11	10	1.08	61	6.37	89	9.27	73	7.40	71	7.65	55	5.59	57	6.10	44	4.73
Class No. 9, 201 to 225 grams.					12	1.30	63	6.58	78	8.13	61	6.18	70	7.54	45	4.57	46	4.92	52	5.59
Class No. 10, 226 to 250 grams.					5	.54	29	3.03	68	7.08	73	7.40	51	5.50	56	5.69	54	5.78	57	6.12
Class No. 11, 251 to 275 grams.					1	.11	27	2.82	46	4.79	52	5.27	60	6.47	60	6.10	48	5.13	53	5.69
Class No. 12, 276 to 300 grams.							8	.84	22	2.29	37	3.75	46	4.96	42	4.27	55	5.88	55	5.91
Class No. 13, 301 to 325 grams.							4	.42	27	2.81	25	2.53	36	3.88	50	5.08	51	5.45	48	5.16
Class No. 14, 326 to 350 grams.							4	.42	18	1.88	32	3.24	34	3.66	36	3.66	40	4.28	40	4.30
Class No. 15, 351 to 375 grams.							3	.31	14	1.46	23	2.33	26	2.80	47	4.78	39	4.17	45	4.83
Class No. 16, 376 to 400 grams.							1	.10	8	.83	19	1.93	28	3.02	29	2.95	33	3.53	28	3.01
Class No. 17, 401 to 425 grams.							2	.21	4	.42	10	1.01	28	3.02	29	2.95	34	3.64	32	3.44
Class No. 18, 426 to 450 grams.									7	.73	18	1.82	27	2.91	26	2.64	30	3.21	14	1.50
Class No. 19, 451 to 475 grams.									3	.31	6	.61	10	1.08	15	1.52	24	2.57	13	1.40
Class No. 20, 476 to 500 grams.									2	.21	4	.41	6	.65	12	1.22	12	1.28	22	2.36
Class No. 21, 501 to 525 grams.									2	.21	6	.61	7	.75	9	.91	11	1.18	17	1.83

Class No. 22, 525 to 550 grams.....																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																
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TABLE III.—Weight and weight percentage of Rural New Yorker potato tubers in each of the 25-gram classes showing the changes in the distribution of the tuber population as the season advanced; after planting on June 13, 1917, at Greeley, Colo.

Weight limits.	Aug. 16.	Aug. 23.	Aug. 30.	Sept. 6.	Sept. 13.	Sept. 20.	Sept. 27.	Oct. 4.	Oct. 11.	Oct. 18.
Class No. 1, 1 to 25 grams.....	8,580	3,460	10.99	Per ct. Grams, 2.40 1,520	Per ct. Grams, 0.96 1,140	Per ct. Grams, 0.81 1,325	Per ct. Grams, 0.53 980	Per ct. Grams, 0.42 910	Per ct. Grams, 0.41 890	Per ct. Grams, 0.39 880
Class No. 2, 26 to 50 grams.....	2,230	11,880	37.73	Per ct. Grams, 9.29 2,350	Per ct. Grams, 2.21 990	Per ct. Grams, .71 1,580	Per ct. Grams, .52 960	Per ct. Grams, .73 1,565	Per ct. Grams, .60 1,460	Per ct. Grams, .65 1,460
Class No. 3, 51 to 75 grams.....	110	1.01	9.830	Per ct. Grams, 31.22 11,620	Per ct. Grams, 5.44 2,030	Per ct. Grams, 1.45 1,945	Per ct. Grams, 1.18 2,180	Per ct. Grams, 1.17 2,520	Per ct. Grams, .74 1,640	Per ct. Grams, .73 1,640
Class No. 4, 76 to 100 grams.....			4,000	Per ct. Grams, 12.70 12,125	Per ct. Grams, 8.81 5,410	Per ct. Grams, 3.86 4,220	Per ct. Grams, 2.60 3,115	Per ct. Grams, 1.72 3,700	Per ct. Grams, 1.59 3,210	Per ct. Grams, 1.42 3,210
Class No. 5, 101 to 125 grams.....			1,840	Per ct. Grams, 5.84 12,625	Per ct. Grams, 12.51 9,705	Per ct. Grams, 6.93 7,970	Per ct. Grams, 4.92 4,080	Per ct. Grams, 2.17 4,670	Per ct. Grams, 1.89 4,380	Per ct. Grams, 1.94 4,380
Class No. 6, 126 to 150 grams.....			140	Per ct. Grams, 44 9,180	Per ct. Grams, 14.50 13,315	Per ct. Grams, 8.95 8,460	Per ct. Grams, 5.22 6,700	Per ct. Grams, 3.19 6,880	Per ct. Grams, 3.02 7,110	Per ct. Grams, 3.15 7,110
Class No. 7, 151 to 175 grams.....			160	Per ct. Grams, 51 4,720	Per ct. Grams, 14.81 10,330	Per ct. Grams, 7.38 11,650	Per ct. Grams, 7.18 7,520	Per ct. Grams, 4.07 7,540	Per ct. Grams, 3.73 6,860	Per ct. Grams, 3.04 6,860
Class No. 8, 176 to 200 grams.....			180	Per ct. Grams, 57 1,765	Per ct. Grams, 10.58 16,345	Per ct. Grams, 11.67 13,700	Per ct. Grams, 8.45 13,030	Per ct. Grams, 7.05 10,080	Per ct. Grams, 4.77 8,080	Per ct. Grams, 3.58 8,080
Class No. 9, 201 to 225 grams.....				Per ct. Grams, 2.79 11,255	Per ct. Grams, 12.40 16,340	Per ct. Grams, 11.67 12,885	Per ct. Grams, 7.95 14,690	Per ct. Grams, 7.95 9,420	Per ct. Grams, 4.39 10,830	Per ct. Grams, 4.80 10,830
Class No. 10, 226 to 250 grams.....				Per ct. Grams, 3.89 13,195	Per ct. Grams, 6.33 15,960	Per ct. Grams, 11.40 17,150	Per ct. Grams, 10.58 11,960	Per ct. Grams, 6.47 13,170	Per ct. Grams, 5.74 13,340	Per ct. Grams, 5.92 13,340
Class No. 11, 251 to 275 grams.....				Per ct. Grams, 1.83 6,730	Per ct. Grams, 6.56 11,900	Per ct. Grams, 8.50 13,500	Per ct. Grams, 8.33 15,590	Per ct. Grams, 8.44 15,420	Per ct. Grams, 5.65 13,700	Per ct. Grams, 6.08 13,700
Class No. 12, 276 to 300 grams.....				Per ct. Grams, .40 6,980	Per ct. Grams, 2,260	Per ct. Grams, 4.44 10,630	Per ct. Grams, 6.56 13,040	Per ct. Grams, 7.06 11,960	Per ct. Grams, 7.08 15,540	Per ct. Grams, 6.89 15,540
Class No. 13, 301 to 325 grams.....				Per ct. Grams, 1,225	Per ct. Grams, 1.15 8,350	Per ct. Grams, 5.96 7,700	Per ct. Grams, 4.75 11,250	Per ct. Grams, 6.09 15,340	Per ct. Grams, 7.18 14,700	Per ct. Grams, 6.52 14,700
Class No. 14, 326 to 350 grams.....				Per ct. Grams, 1,360	Per ct. Grams, 1.28 6,000	Per ct. Grams, 4.28 10,690	Per ct. Grams, 6.60 11,420	Per ct. Grams, 6.18 12,020	Per ct. Grams, 6.07 13,280	Per ct. Grams, 5.89 13,280
Class No. 15, 351 to 375 grams.....				Per ct. Grams, 1,075	Per ct. Grams, 1.01 5,040	Per ct. Grams, 3.60 8,240	Per ct. Grams, 5.08 9,370	Per ct. Grams, 5.07 16,860	Per ct. Grams, 6.34 16,110	Per ct. Grams, 7.15 16,110
Class No. 16, 376 to 400 grams.....				Per ct. Grams, 400	Per ct. Grams, .38 3,040	Per ct. Grams, 2.17 7,360	Per ct. Grams, 4.54 10,820	Per ct. Grams, 5.85 11,120	Per ct. Grams, 5.76 10,750	Per ct. Grams, 4.77 10,750
Class No. 17, 401 to 425 grams.....				Per ct. Grams, 810	Per ct. Grams, .76 1,620	Per ct. Grams, 1.16 4,140	Per ct. Grams, 2.55 11,450	Per ct. Grams, 6.20 11,800	Per ct. Grams, 6.26 13,020	Per ct. Grams, 5.78 13,020
Class No. 18, 426 to 450 grams.....				Per ct. Grams,	Per ct. Grams,	Per ct. Grams, 2.16 7,910	Per ct. Grams, 4.88 11,680	Per ct. Grams, 6.32 11,200	Per ct. Grams, 5.87 6,080	Per ct. Grams, 2.70 6,080
Class No. 19, 451 to 475 grams.....				Per ct. Grams,	Per ct. Grams,	Per ct. Grams, 1.00 2,760	Per ct. Grams, 1.70 4,570	Per ct. Grams, 2.47 6,890	Per ct. Grams, 5.02 5,930	Per ct. Grams, 2.63 5,930
Class No. 20, 476 to 500 grams.....				Per ct. Grams,	Per ct. Grams,	Per ct. Grams, .69 1,930	Per ct. Grams, 1.19 2,880	Per ct. Grams, 1.56 5,760	Per ct. Grams, 2.64 10,590	Per ct. Grams, 4.70 10,590
Class No. 21, 501 to 525 grams.....				Per ct. Grams,	Per ct. Grams,	Per ct. Grams, .71 3,060	Per ct. Grams, 1.89 3,540	Per ct. Grams, 1.92 4,560	Per ct. Grams, 2.52 8,550	Per ct. Grams, 3.79 8,550
Class No. 22, 526 to 550 grams.....				Per ct. Grams,	Per ct. Grams,	Per ct. Grams, 0 1,060	Per ct. Grams, .65 3,720	Per ct. Grams, 2.01 6,900	Per ct. Grams, 3.63 6,870	Per ct. Grams, 3.05 6,870

Class No. 23, 551 to 575 grams.....					0	0	1, 120	.69	3, 910	2.12	3, 890	1.81	3, 880	1.76	8, 940	3.97		
Class No. 24, 576 to 600 grams.....					0	0	1, 160	.72	4, 080	2.21	3, 470	1.61	4, 120	1.87	2, 880	1.28		
Class No. 25, 601 to 625 grams.....					0	0	0	.....	0	0	1, 810	.84	3, 020	1.37	4, 200	1.86		
Class No. 26, 626 to 650 grams.....					0	0	0	.....	0	0	3, 780	1.75	1, 270	.57	1, 280	.57		
Class No. 27, 651 to 675 grams.....					0	0	0	.....	670	.36	3, 920	1.82	2, 640	1.20	2, 610	1.16		
Class No. 28, 676 to 700 grams.....					0	0	0	.....	0	0	2, 070	.96	1, 370	.62	2, 060	.91		
Class No. 29, 701 to 725 grams.....					0	0	0	.....	0	0	710	.33	2, 080	.91	2, 120	.94		
Class No. 30, 726 to 750 grams.....					725	.52	.....	.....	0	0	740	.34	740	.34	4, 350	1.93		
Class No. 31, 751 to 775 grams.....					.....	.....	.....	.....	0	0	3, 010	1.40	0	0	760	.34		
Class No. 32, 776 to 800 grams.....					.....	.....	.....	.....	790	.43	0	0	0	0	800	.35		
Class No. 33, 801 to 825 grams.....					.....	.....	.....	.....	815	.44	820	.38	0	0	820	.36		
Class No. 34, 826 to 850 grams.....					.....	.....	.....	.....	.....	.....	0	0	0	0	840	.37		
Class No. 35, 851 to 875 grams.....					.....	.....	.....	.....	.....	.....	0	0	0	0	880	.39		
Class No. 36, 876 to 900 grams.....					.....	.....	.....	.....	.....	.....	0	0	0	0	.....	.....		
Class No. 37, 901 to 925 grams.....					.....	.....	.....	.....	.....	.....	900	.42	0	0	.....	.....		
Class No. 38, 926 to 950 grams.....					.....	.....	.....	.....	.....	.....	.....	.....	0	0	.....	.....		
Class No. 39, 951 to 975 grams.....					.....	.....	.....	.....	.....	.....	.....	.....	0	0	.....	.....		
Class No. 40, 976 to 1,000 grams.....					.....	.....	.....	.....	.....	.....	.....	.....	0	0	.....	.....		
Total.....	10, 930	100	31, 490	100	63, 310	100	106, 400	100	140, 055	100.02	162, 145	100.02	184, 810	100.03	215, 405	99.99	225, 460	100

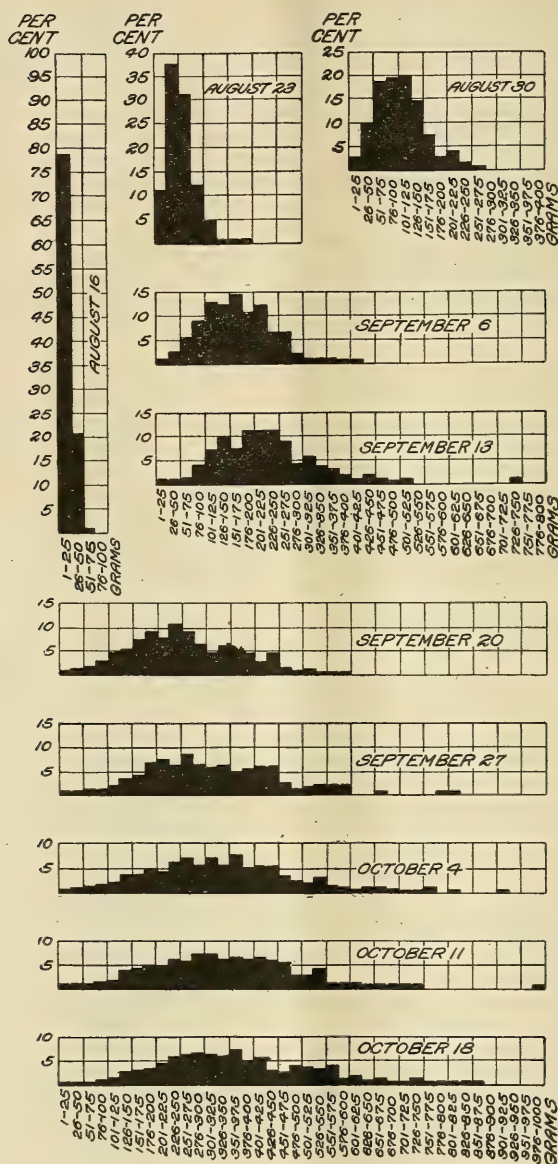


FIG. 8.—Diagram showing the percentage of tubers by classes, differing in weight by 25 grams, found in the tuber population of 200 hills at each date of digging.

LENGTH OF STOLON AND ITS POSITION ON THE STEM AS RELATED TO THE SIZE OF THE TUBER.

The experiments of 1917 had shown that there was great inequality in the rate of growth and consequently in the size of the tubers. To determine whether this condition was associated with the length of the stolon which bears the tuber and its position on the stem, 55 hills were dug in the fall of 1918, after the plants had reached maturity, and the stolons were measured and the tubers weighed. The variety used for this purpose was the Charles Downing. Early in the season, before the tubers had begun to set, the plants were thinned to a single stem, to avoid influences which might arise from the presence of several stems in the hill. All the measurements and weights obtained are shown in Table IV.

TABLE IV.—*Length of each stolon and weight of the tuber which it produced in 55 hills of Charles Downing potatoes grown at Greeley, Colo., in 1918.*

[The stolons in each hill are numbered in accordance with their relative position on the stem of the plant, beginning with the lowest.]

Plant and stolon.	Length of stolon.	Weight of tuber.	Plant and stolon.	Length of stolon.	Weight of tuber.
Plant No. 1:	<i>Mm.</i>	<i>Grams.</i>	Plant No. 12:	<i>Mm.</i>	<i>Grams.</i>
Stolon 1.....	15	0	Stolon 1.....	100	125
Stolon 2.....	54	247	Stolon 2.....	124	115
Stolon 3.....	65	335	Stolon 3.....	63	110
Plant No. 2:			Stolon 4.....	147	226
Stolon 1.....	50	0	Plant No. 13:		
Stolon 2.....	15	100	Stolon 1.....	146	191
Stolon 3.....	85	340	Stolon 2.....	148	138
Stolon 4.....	18	38	Stolon 3.....	205	110
Stolon 5.....	86	38	Stolon 4.....	130	13
Stolon 6.....	77	7	Plant No. 14:		
Plant No. 3:			Stolon 1.....	50	68
Stolon 1.....	12	115	Stolon 2.....	110	150
Stolon 2.....	30	94	Stolon 3.....	80	162
Stolon 3.....	42	67	Plant No. 15:		
Stolon 4.....	50	112	Stolon 1.....	34	264
Plant No. 4:			Stolon 2.....	163	154
Stolon 1.....	5	325	Plant No. 16:		
Stolon 2.....	45	120	Stolon a ⁽¹⁾	130	283
Plant No. 5:			Stolon 3.....	85	218
Stolon a ⁽¹⁾	54	256	Stolon 4.....	186	46
Stolon a ⁽²⁾	34	33	Stolon 4.....	112	12
Plant No. 6:			Plant No. 17:		
Stolon 1.....	2	197	Stolon 1.....	91	122
Stolon 2.....	27	1	Stolon 2.....	107	121
Stolon 3.....	155	175	Stolon 3.....	90	143
Plant No. 7:			Stolon 4.....	62	124
Stolon 1.....	12	160	Plant No. 18:		
Stolon 2.....	35	150	Stolon 1.....	22	199
Stolon 3.....	83	151	Stolon 2.....	95	203
Plant No. 8:			Plant No. 19:		
Stolon 1.....	4	125	Stolon a ⁽¹⁾	25	84
Stolon 2.....	23	0	Stolon a ⁽²⁾	3	86
Stolon 3.....	17	27	Stolon 3.....	70	142
Stolon 4.....	113	193	Plant No. 20:		
Plant No. 9:			Stolon 1.....	162	130
Stolon 1.....	115	103	Stolon 2.....	58	0
Stolon 2.....	125	123	Stolon 3.....	80	235
Stolon 3.....	75	23	Plant No. 21:		
Plant No. 10:			Stolon 1.....	34	241
Stolon 1.....	25	446	Stolon 2.....	17	137
Stolon 2.....	18	103	Plant No. 22:		
Stolon 3.....	17	0	Stolon 1.....	77	383
Stolon 4.....	30	0	Stolon a ⁽²⁾	305	119
Stolon 5.....	17	151	Stolon a ⁽³⁾	170	258
Plant No. 11:			Plant No. 23:		
Stolon 1.....	27	88	Stolon 1.....	25	266
Stolon 2.....	36	120	Stolon 2.....	23	114
Stolon 3.....	30	70	Stolon 3.....	127	177

a Both stolons arising from the same node.

TABLE IV.—Length of each stolon and weight of the tuber which it produced in 55 hills of Charles Downing potatoes grown at Greeley, Colo., in 1918—Continued.

Plant and stolon.	Length of stolon.	Weight of tuber.	Plant and stolon.	Length of stolon.	Weight of tuber.
Plant No. 24:	<i>Mm.</i>	<i>Grams.</i>	Plant No. 39:	<i>Mm.</i>	<i>Grams.</i>
Stolon 1.....	42	120	Stolon 1.....	38	90
Stolon 2.....	18	169	Stolon 2.....	87	71
Stolon 3.....	115	123	Stolon 3.....	96	140
Plant No. 25:			Stolon 4.....	120	88
Stolon 1.....	32	202	Plant No. 40:		
Stolon 2.....	71	143	Stolon 1.....	112	193
Plant No. 26:			Stolon 2.....	30	63
Stolon 1.....	110	44	Plant No. 41:		
Stolon 2.....	32	70	Stolon 1.....	78	74
Stolon 3.....	46	134	Stolon 2.....	63	130
Stolon 4.....	113	91	Plant No. 42:		
Stolon 5.....	126	56	Stolon 1.....	43	87
Plant No. 27:			Stolon a ²	102	97
Stolon 1.....	82	123	Stolon a ³	77	31
Stolon 2.....	58	277	Stolon a ⁴	90	145
Stolon 3.....	14	103	Stolon a ⁵	48	92
Stolon 4.....	160	16	Stolon 6.....	141	47
Plant No. 28:			Plant No. 43:		
Stolon 1.....	13	326	Stolon 1.....	33	184
Stolon a ²	15	78	Stolon 2.....	86	303
Stolon a ³	162	258	Plant No. 44:		
Plant No. 29:			Stolon 1.....	91	317
Stolon 1.....	25	95	Stolon 2.....	100	158
Stolon 2.....	53	171	Plant No. 45:		
Stolon 3.....	95	107	Stolon 1.....	116	193
Plant No. 30:			Stolon 2.....	66	210
Stolon a ¹	19	174	Plant No. 46:		
Stolon a ²	176	103	Stolon 1.....	68	196
Stolon 3.....	157	52	Stolon 2.....	90	183
Stolon 4.....	120	116	Stolon 3.....	116	66
Plant No. 31:			Plant No. 47:		
Stolon 1.....	71	130	Stolon 1.....	102	139
Stolon 2.....	180	93	Stolon 2.....	79	175
Stolon 3.....	83	120	Plant No. 48:		
Stolon 4.....	175	80	Stolon 1.....	77	337
Plant No. 32:			Stolon 2.....	53	27
Stolon 1.....	63	78	Stolon 3.....	122	114
Stolon 2.....	28	222	Plant No. 49:		
Stolon 3.....	71	196	Stolon 1.....	56	155
Stolon 4.....	135	33	Stolon 2.....	57	280
Plant No. 33:			Plant No. 50:		
Stolon 1.....	62	240	Stolon 1.....	58	80
Stolon 2.....	82	125	Stolon 2.....	63	124
Plant No. 34:			Stolon 3.....	152	124
Stolon 1.....	71	116	Stolon 4.....	48	115
Stolon 2.....	66	175	Plant No. 51:		
Plant No. 35:			Stolon 1.....	48	379
Stolon 1.....	41	275	Stolon 2.....	51	150
Stolon 2.....	119	12	Plant No. 52:		
Plant No. 36:			Stolon 1.....	4	115
Stolon 1.....	8	305	Stolon 2.....	92	170
Stolon 2.....	32	220	Stolon 3.....	90	104
Stolon 3.....	86	194	Plant No. 53:		
Plant No. 37:			Stolon 1.....	81	49
Stolon 1.....	53	140	Stolon 2.....	16	112
Stolon 2.....	66	125	Stolon 3.....	37	141
Stolon 3.....	88	92	Plant No. 54:		
Stolon 4.....	75	118	Stolon 1.....	98	130
Plant No. 38:			Stolon 2.....	2	240
Stolon 1.....	100	408	Plant No. 55:		
Stolon 2.....	63	56	Stolon 1.....	156	160
Stolon 3.....	281	184	Stolon 2.....	32	380

a Both stolons arising from the same node.

To determine whether any relation exists between stolon length and tuber weight, the data shown in Table IV have been brought together in correlation form in Table V.

While there appears to be a slight trend toward negative correlation, the coefficient of -0.112 is but little more than twice the probable error; therefore it is to be regarded as having little signifi-

cance, so that the data present no conclusive evidence to show that the weight of the tuber is dependent upon the length of the stolon which bears it.

TABLE V.—*Correlation between the length of each stolon and the weight of the tuber which it produced in 55 hills of Charles Downing potatoes grown at Greeley, Colo., in 1918.*

[Coefficient of correlation, -0.112 ± 0.052 .]

Length of stolons (mm.).	Weight of tubers (grams).																		Frequency.
	1 to 25	26 to 50	51 to 75	76 to 100	101 to 125	126 to 150	151 to 175	176 to 200	201 to 225	226 to 250	251 to 275	276 to 300	301 to 325	326 to 350	351 to 375	376 to 400	401 to 425	426 to 450	
1 to 25.....	.....	2	.....	5	7	1	4	2	.....	1	1	.....	2	1	.....	.....	.....	1	27
26 to 50.....	1	1	5	5	5	3	.....	1	3	1	2	.....	.....	.....	.....	2	.....	.....	29
51 to 75.....	1	1	1	2	5	6	3	2	1	2	1	2	.....	1	.....	.....	.....	.....	28
76 to 100.....	1	3	2	1	8	4	5	2	2	1	.....	.....	2	2	.....	1	1	.....	35
101 to 125.....	2	1	1	3	7	2	.....	3	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	19
126 to 150.....	1	2	1	.....	.....	1	.....	2	.....	1	.....	1	.....	.....	.....	.....	.....	.....	9
151 to 175.....	1	.....	1	1	1	1	3	.....	.....	.....	2	.....	.....	.....	.....	.....	.....	.....	10
176 to 200.....	.....	1	.....	1	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	3
201 to 225.....	.....	.....	.....	.....	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1
226 to 250.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0
251 to 275.....	.....	.....	.....	.....	.....	.....	.....	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0
276 to 300.....	.....	.....	.....	.....	.....	.....	.....	.....	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	1
301 to 325.....	.....	.....	.....	.....	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1
Frequency.....	7	11	11	18	36	18	15	13	6	6	6	3	4	4	0	3	1	1	163

A further study of the data for the purpose of ascertaining whether the length of the stolon and the size of the tuber are associated with a definite position on the stem, included a grouping of the plants having two, three, and four stolons, respectively, using only those in which one tuber was produced at each node. The summarized results are shown in Table VI.

TABLE VI.—*Relation of the position of the stolon on the stem to the length of each stolon and the weight of the tuber which it produced, in 55 hills of Charles Downing potatoes grown at Greeley, Colo., in 1918.*

Position of the stolon.	Number of hills.	Length of the stolon.	Weight of the tuber.
Two stolons per hill:		Mm.	Grams.
Lower stolon.....	18	66.2	210.3
Upper stolon.....	18	68.0	175.4
Three stolons per hill:			
Lower stolon.....	14	45.4	179.1
Middle stolon.....	14	55.2	126.1
Upper stolon.....	14	106.6	127.9
Four stolons per hill:			
Lower stolon.....	10	71.4	119.4
Second stolon.....	10	89.1	138.0
Third stolon.....	10	90.4	120.5
Upper stolon.....	10	110.2	92.5

It will be seen that while the original tabulations (Table IV) show considerable fluctuation, the averages brought together in Table VI indicate very consistently a high degree of relationship between the position of the stolon and its length, the shortest stolons being

produced at the base of the stem, with a gradual increase in length in the upper positions. Since only one variety was included in this phase of the experiment, further studies with other varieties are necessary to determine the general applicability of these results.

With respect to the size of the tuber, the greatest average weight was produced by the lowest stolons in the 2-stolon and 3-stolon groups; while in the 4-stolon group the maximum production was in the second position, with a gradual decrease in the weight in the upper stolons. Larger numbers of observations, however, are needed to establish the laws governing these relationships.

SIZE AND CHARACTER OF SEED PIECES AS RELATED TO TUBER PRODUCTION.

Experiments were conducted to determine to what extent tuber production is influenced by the size of the seed piece; also to determine the relative influence of whole and cut seed. The tubers used for these studies consisted of 1, 2, 3, 4, 5, and 6 ounce sizes of the Rural New Yorker variety. One lot was planted whole, another cut in halves, and the remaining lot quartered. The hills were 16 inches apart in the row, with rows 36 inches apart. The series was duplicated and the work relating to the problem under discussion carried on for two years, 1916 and 1917.

Since the results of these experiments will be published in detail in another report, only a brief summary, which includes the averages of such data as bear directly on this question for the two years, will be given at this time (Tables VII and VIII).³

TABLE VII.—*Relation of the size and kind of seed piece to the number and weight of tubers per hill and per stem as shown in tests of the Rural New Yorker variety of potatoes grown at Greeley, Colo., in 1916 and 1917.*

Size of tubers.	Weight of seed piece planted (ounces).	Number of stems per hill.	Number of tubers.		Weight of tubers (grams).	
			Per hill.	Per stem.	Per hill.	Per stem.
Planted whole:						
1 ounce.....	1	1.76	4.25	2.41	712.72	404.80
2 ounces.....	2	2.60	6.31	2.42	876.55	336.74
3 ounces.....	3	3.22	7.18	2.23	886.23	274.85
4 ounces.....	4	3.72	7.96	2.14	952.92	255.86
5 ounces.....	5	4.51	9.22	2.04	986.59	218.65
6 ounces.....	6	5.03	10.11	2.01	1,030.31	204.70
Tubers cut in halves:						
2 ounces.....	1	1.81	3.99	2.20	668.61	368.89
3 ounces.....	1½	2.25	4.79	2.12	764.90	339.32
4 ounces.....	2	2.50	5.29	2.12	815.51	326.65
5 ounces.....	2½	2.63	5.61	2.13	785.78	298.45
6 ounces.....	3	3.05	6.28	2.06	836.54	274.14
Tubers cut in quarters:						
3 ounces.....	¾	1.49	3.35	2.25	663.84	444.84
4 ounces.....	1	1.63	3.63	2.23	673.25	413.20
5 ounces.....	1¼	1.85	3.94	2.13	724.54	390.91
6 ounces.....	1½	1.96	4.13	2.11	737.56	375.95

³ The calculations of the data used in these tables are based on the total number of individuals for 1916 and 1917 rather than the average for the two years, so that they give the true averages for the entire period of the experiment.

A study of Table VII shows that both the number and the weight of tubers per hill varied directly with the size of the seed piece planted. There was also a corresponding increase in the number of stems per hill. If, however, we consider the stem rather than the hill as the unit for comparison, we find that the number of tubers which set per stem was affected in only a very small degree by the size of the seed piece, though the general trend was toward a slight decrease in the number of tubers produced as the size of the seed increased. The effect on the weight of the tubers per stem was much more pronounced, as there was a very consistent and well-defined decrease associated with increase in the size of the seed. It is apparent that the food supply was not sufficient to maintain the needs of the increased number of stems for maximum tuber production.

TABLE VIII.—*Relative influence of whole and cut seed on tuber production as shown by the results with different kinds of seed where seed pieces of the same weight were used in tests of the Rural New Yorker variety of potatoes grown at Greeley, Colo., in 1916 and 1917.*

Size and kind of seed.	Weight of seed piece planted (ounces).	Number of stems per hill.	Number of tubers.		Weight of tubers (grams).	
			Per hill.	Per stem.	Per hill.	Per stem.
1 ounce, whole.....	1	1.76	4.25	2.41	712.72	404.80
2 ounce, halved.....		1.81	3.99	2.20	668.61	368.89
4 ounce, quartered.....		1.63	3.63	2.23	673.25	413.20
2 ounce, whole.....	2	2.60	6.31	2.42	876.55	336.74
4 ounce, halved.....		2.50	5.29	2.12	815.51	326.65
3 ounce, whole.....	3	3.22	7.18	2.23	886.23	274.85
6 ounce, halved.....		3.05	6.28	2.06	836.54	274.14
3 ounce, halved.....	1½	2.25	4.79	2.12	764.90	339.32
6 ounce, quartered.....		1.96	4.13	2.11	737.56	375.95

Comparisons of the results obtained from whole and cut seed recorded in Table VIII show a slightly larger number and, with one exception, a larger weight of tubers per stem where whole seed was used.

RELATION OF VARIETY TO TUBER PRODUCTION.

It is a matter of common observation that the tuber-producing ability of different varieties varies considerably with respect to the number and the weight of tubers per hill as well as other characteristics. This is brought out very clearly in the curves shown in figures 9 and 10. The data on which these are based were obtained in 1915 from 500 hills each of the Pearl and Rural New Yorker varieties taken from adjacent plats which were grown under conditions as nearly identical as possible.

A study of the curves for the number of tubers (fig. 9) shows an entirely different distribution for the two varieties. In the Rural

New Yorker there was a very decided grouping around the model class, 22.2 per cent of the entire number of hills falling in this class and 61.2 per cent in the 3, 4, and 5 tuber classes. In the Pearl there was a much wider range of variability, with a considerable number

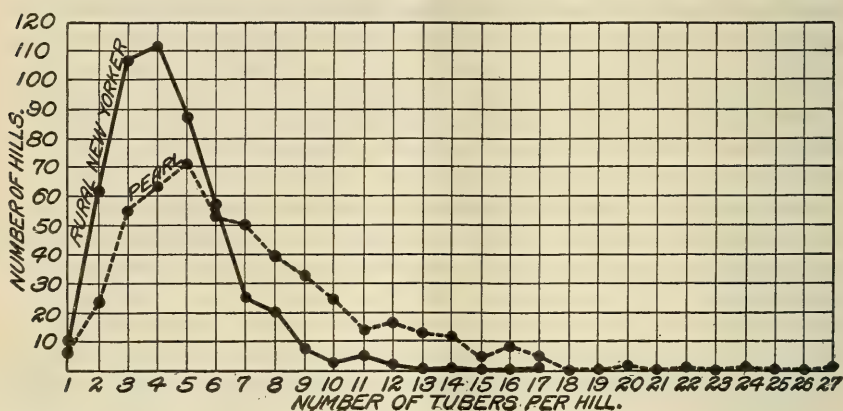


FIG. 9.—Diagram showing the number of tubers per hill produced in 500 hills of Rural New Yorker (average, 4.5) and 500 hills of Pearl (average, 6.9).

of the individuals in the intermediate classes. The average hill production of this variety was 2.4 tubers greater than that of the Rural New Yorker.

The curves for weight of tubers per hill (fig. 10) show that there was much greater uniformity in production in the Rural New Yorker.

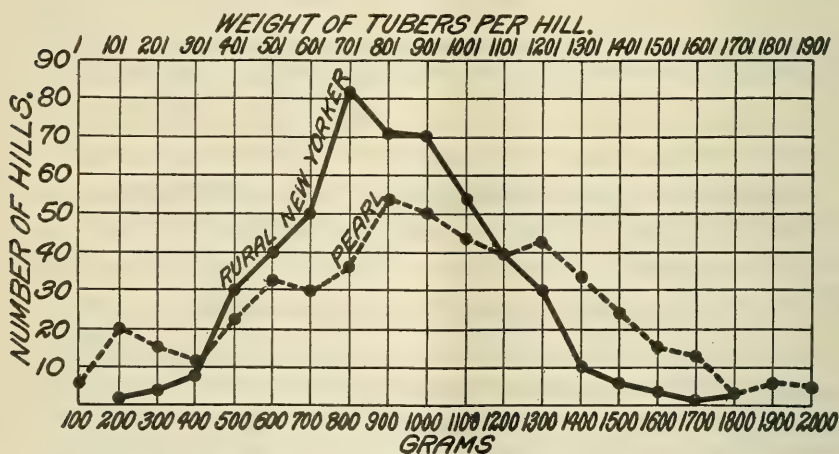


FIG. 10.—Diagram showing the weight of tubers per hill produced in 500 hills of Rural New Yorker (average, 860.7 grams) and 500 hills of Pearl (average, 944 grams).

The Pearl, however, produced the larger average yield, the weight per hill exceeding that of the Rural New Yorker by 83.3 grams.

A further comparison of the behavior of different varieties of potatoes under varying treatment respecting irrigation is shown in Table

IX, particularly in the averages of the data obtained in 1917. The variation in tuber production according to variety is there clearly shown, the number of tubers per hill ranging from 3.8 in the Rural New Yorker to 7.1 in the Charles Downing. The lowest average weights per hill were produced by the two early varieties, Triumph and Early Ohio, and the highest by the Pearl, which is a late variety.

TABLE IX.—*Effect of irrigation on the average number and the average weight of the tubers of different varieties of potatoes grown at Greeley, Colo., in 1917 and 1918.*

Year and variety.	Number of tubers per hill.					Weight of tubers per hill (grams).				
	No irri- gation.	First irriga- tion after tubers had begun to set.	Irrigation started before tubers had begun to set.		Aver- age.	No irri- gation.	First irriga- tion after tubers had begun to set.	Irrigation started before tubers had begun to set.		Aver- age.
			Medium number of irri- gations.	Many irriga- tions.				Medium number of irri- gations.	Many irriga- tions.	
Experiments in 1917:										
Triumph.....	4.4	3.9	7.8	5.9	5.5	459.8	697.2	1,060.7	702.0	729.9
Early Ohio.....	3.2	4.2	6.3	6.7	4.8	413.0	712.3	928.3	1,145.0	730.6
Charles Downing	5.1	7.1	9.4	6.6	7.1	446.3	830.3	1,005.7	811.3	773.4
Pearl.....	5.3	5.1	6.2	7.7	6.1	528.0	887.8	1,036.3	1,137.7	897.5
Rural New										
Yorker.....	3.5	3.2	4.3	4.2	3.8	533.5	759.8	876.7	884.7	763.7
Russet Burbank.	3.6	4.2	6.5	6.2	5.1	425.7	826.7	974.3	868.3	773.8
Peachblow.....	4.5	5.6	6.9	9.0	6.5	433.7	867.0	991.3	926.7	804.7
Average.....	4.2	4.8	6.8	6.6	.....	462.9	797.3	981.9	925.1	.....
Experiments in 1918:										
Triumph.....	3.6	3.1	3.1	3.6	3.4	269.0	266.3	317.5	365.1	304.5
Late Ohio.....	3.3	3.1	3.0	3.6	3.5	374.2	482.2	675.9	654.1	546.6
Charles Downing	5.1	5.0	6.5	6.6	5.8	342.9	420.5	589.7	655.9	502.3
Pearl.....	3.3	3.5	3.3	3.7	3.5	399.2	490.3	610.1	676.3	544.0
Rural New										
Yorker.....	3.4	3.8	4.3	4.0	3.9	324.3	475.4	645.5	652.3	524.4
Average.....	3.7	3.7	4.2	4.3	.....	341.9	426.9	567.7	600.7	.....

CHARACTER OF SOIL AS RELATED TO TUBER PRODUCTION.

In 1918 experiments were conducted for the purpose of determining to what extent, if any, tuber production is influenced by the type of soil. Two varieties, the Triumph and the Rural New Yorker, were used for these studies. The seed for each variety, which was obtained from a single source, was divided into three lots. One lot of each variety was grown on the farm of Mr. W. M. Wilson,⁴ on a very heavy clay soil classified as "Billings clay loam (3);" a second lot was grown on the experiment station farm on a clay-loam soil designated as "Fort Collins loam (3);" the remaining lot was grown on the farm of Mr. W. R. McClellan⁴ on a sandy loam known as "Colorado fine sandy loam (3)."

The crops on all plats were grown under practical field conditions, the cultivation and irrigation practices following the methods in gen-

⁴The writer is indebted to W. M. Wilson and W. R. McClellan for their cooperation in growing the experimental crops produced on the heavy clay and fine sandy loam, respectively.

eral use on the soils in question. After the crop had reached maturity 400 hills of each crop were dug, the tubers counted, and the weight for each hill obtained. The results are given in Table X.

TABLE X.—*Relation of soil type to the number and the weight of tubers as shown in tests of two varieties of potatoes grown under field conditions near Greeley, Colo., in 1918.*

Character of the soil.	Triumph variety.			Rural New Yorker variety.		
	Number of tubers per hill.	Weight of tubers (grams).		Number of tubers per hill.	Weight of tubers (grams).	
		Per hill.	Average.		Per hill.	Average.
Heavy clay.....	3.1	194.6	62.0	3.0	376.7	125.3
Clay loam.....	4.2	387.2	93.3	4.9	663.7	136.5
Fine sandy loam.....	5.9	489.4	83.3	6.3	1,033.5	162.8

The lowest production of tubers with respect to both number and weight per hill was on the heaviest soil, while the highest numbers and yields were produced on the lightest soil, indicating a tendency toward an increase in the productivity of the plant as the character of the soil changes toward the lighter types. Since these results cover only a single season, it is possible that the relationships found to exist in this experiment might be modified somewhat under different climatic conditions as well as by differences in the relative state of productivity of the different soil types. The data do, however, show very conclusively the influence of the character of the soil on tuber production.

TIME AND NUMBER OF IRRIGATIONS AS RELATED TO TUBER PRODUCTION.

The material used for the study of the relation of irrigation methods to tuber production consisted in 1917 of one row each of seven varieties divided into four sections. The first received no irrigation. On the second section irrigation was not begun until after tuber formation was well started. On the third and fourth sections the first applications of water were before tuber formation had started. On the fourth section the number of irrigations was somewhat in excess of what would be considered the optimum in commercial field practice. At the time of harvest 30 hills were dug from each section of each row (except in the fourth section of the Early Ohio, where disease reduced the number of healthy hills to 10), and the hills were weighed and the tubers counted.

In 1918 practically the same plan was followed, except that the number of varieties was reduced to five, and each section of each variety consisted of two full rows of approximately 200 hills each. The effects of the early irrigations in this season were to some extent counterbalanced by a relatively large rainfall between the periods of germination and the beginning of tuber formation.

The dates of irrigation in both 1917 and 1918 are shown in Table XI. The number and the weights of tubers have already been shown (Table IX). Considering the averages of all the varieties for each year, it is found that in both seasons the early application of water, before tuber formation had started, resulted in an increase in the number of tubers as well as in the weight per hill. Starting irrigation late in the season materially increased the weight over that produced on the nonirrigated plats. On the other hand, very little difference is shown in the number of tubers per hill produced under the two conditions. In 1917 a slight increase was indicated, but the small number of individuals involved raises the question whether so small a difference may not be due to so-called experimental error. Where irrigation was started before the tubers had begun to form, increasing the number of irrigations did not increase the number of tubers. In 1918 one extra irrigation increased the weight of tubers 33 grams per hill, while in 1917 four extra irrigations resulted in a decrease in weight. Apparently the quantity of water applied in this case was in excess of the optimum requirements of the plants. The results in general, while not of sufficient extent to warrant final conclusions, indicate that each application of water, at almost any period in the growth of the plant, provided excessive quantities are not used, may be expected to produce an increase in the weight of the crop, but that little or no increase in the number of tubers is likely to result from irrigation after tuber formation is well started.

TABLE XI.—*Dates of irrigation in 1917 and 1918 as related to the production of potato tubers of different varieties grown at Greeley, Colo., in 1917 and 1918.*

Treatment.	Experiments in 1917.				Experiments in 1918.		
	June.	July.	August.	September.	July.	August.	September.
First irrigation after tubers had begun to set.....			14, 19, and 31.	7		21	4
Irrigation begun early, medium number.....		27	...do...	7	6	8, 15, and 30.	4
Irrigation begun early, many irrigations.....	21	3, 15, 21, and 27.	...do...	7	6	8, 15, 25, and 30.	4

SUMMARY.

The time of the beginning of tuber formation was found to coincide very closely with the end of the period of flower-bud development.

The statistical studies of tubers at 1-week intervals showed that the greater part of those which grew to exceed half an inch in diameter were formed at the beginning of the period of tuber development.

The maximum rate of growth of the tubers was found to occur about the last of August or first of September, which was approxi-

mately 80 days after planting. At this time nearly one-third of the total period of tuber development had been completed.

The differences in the sizes of tubers in the individual hill are attributed largely to the unequal rate of growth rather than to differences in the age of the tubers.

A small increase in the weight of tubers was found to occur after the vines had been killed by frost.

The weight of the tuber does not appear to be correlated with the length of the stolon upon which it is produced.

The average data show a tendency toward a decrease in the size of the tuber on the upper stolons, though the individual plants showed considerable diversity in this respect.

The number and the weights of tubers per hill were found to be influenced by the size and the kind of the seed piece planted.

Well-defined differences were found in the tuber-producing capacity of different varieties when grown under similar conditions.

The experiments on different types of soil showed that a close relationship exists between the character of the soil and the number and the weight of tubers. The largest numbers and weights were produced on the lighter types of soil.

The irrigation experiments, while not carried to a final conclusion, indicated that the application of water before tuber formation had begun increased the number of tubers. Increasing the number of irrigations appears to have had little effect on the number of tubers. The weight per hill, however, was increased by each additional irrigation except where the applications were too frequent.

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PROFESSIONAL PAPER

October 8, 1921

EXPERIMENTS AND SUGGESTIONS FOR THE CONTROL OF THE CODLING MOTH IN THE GRAND VALLEY OF COLORADO.¹

By E. H. SIEGLER, *Entomologist*, and H. K. PLANK,² *Scientific Assistant, Fruit Insect Investigations, in cooperation with the Colorado Agricultural Experiment Station.*

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Owing to the great abundance and destructiveness of the codling moth (*Laspeyresia pomonella* L.) in the Grand Valley of Colorado, the Bureau of Entomology of the United States Department of Agriculture, in cooperation with the Colorado Agricultural Experiment Station, undertook in 1915 a study of its life history and control. The biological study was concluded the following year, but the control investigations continued during 1916, 1917, and 1918.

In this report are given the more important results of the spraying experiments and some suggestions for the control of the codling moth in the Grand Valley.

¹ In 1915 and 1916 the senior author was in immediate charge, assisted by E. R. Van Leeuwen, of the Bureau of Entomology, during the former season and by H. K. Plank, also of the bureau, during the latter. In 1917 Mr. Plank had charge of the project, assisted by Leo C. Antles, of the Colorado Agricultural Experiment Station, and during the following year Mr. Antles carried out the experiments under the general direction of Mr. Plank and the Colorado Experiment Station.

Dr. A. L. Quaintance, in charge of fruit insect investigations, Bureau of Entomology, and Dr. C. P. Gillette, George M. List, and Claude Wakeland, of the Colorado Agricultural Experiment Station, made many helpful suggestions throughout the course of the work. The writers also wish to express their appreciation for the cooperation of the Grand Valley fruit growers.

² Resigned June 30, 1920.

THE GRAND VALLEY OF COLORADO.

The Grand Valley is one of the most important fruit-growing regions of Colorado, having approximately 15,000 acres devoted to such fruits as apples, pears, peaches, plums, cherries, and bush fruits. About 10,000 of these acres are planted to apples and 2,500 to pears, both of which (and particularly the apple) are heavily attacked by the codling moth.

LOCATION AND TOPOGRAPHY.

The Grand Valley is in the western part of Mesa County and extends from Palisades to Fruita, about 32 miles. The valley follows the course of the Grand River and is generally level, except for the sections known as the Fruit Ridges, which are somewhat elevated and rolling. The district of Orchard Mesa, although higher than the rest of the valley, is typical level, or mesa, land. The lower part of the valley is approximately 4,500 feet above sea level and the upper district at Palisades is about 4,800 feet in elevation.

CLIMATE.

The climate is comparatively dry, and the crops are irrigated principally by means of water taken from the Grand River. The annual precipitation is but 8 to 9 inches, and during the five months from May to September, in which season the apple and codling moth are developing, the rainfall amounts to only from 3 to 4 inches. The mean normal temperature during the same period is about 70.6° F.

COMPARISON OF THE CLIMATIC CONDITIONS OF GRAND JUNCTION, COLO., AND ROCHESTER, N. Y.³

Since the development and severity of the codling moth are largely influenced by climatic factors, it may be of interest to compare the weather conditions of the Grand Valley with those of the western New York apple belt. Under the semiarid conditions that exist in the Grand Valley, the codling moth causes great injury to the fruit crop and is very difficult to control, whereas under the relatively cooler and more humid conditions of western New York the codling moth is much less troublesome.

In Table 1 will be found data giving a comparison of the mean normal temperature and precipitation of Grand Junction, Colo., and Rochester, N. Y.⁴ It will be noted therein that the total normal precipitation in the Grand Valley during the growing season, or from May to September, inclusive, is only about one-fourth as much as in western New York and that the mean temperature is about 6° F. higher than that of Rochester, N. Y.

³ Grand Junction, Colo., is the approximate center of the Grand Valley, and Rochester, N. Y., is in the midst of the western New York apple belt.

⁴ Climatological data, U. S. Weather Bureau.

TABLE 1.—*Comparison of mean normal temperature and precipitation, Grand Junction, Colo., and Rochester, N. Y.*

Month.	Grand Junction, Colo.		Rochester, N. Y.	
	Mean normal temper- ature.	Mean normal precipi- tation.	Mean normal temper- ature.	Mean normal precipi- tation.
	° F.	Inches.	° F.	Inches.
May.....	58.9	0.92	56.7	2.94
June.....	72.6	0.40	65.9	3.13
July.....	79.2	0.50	70.4	3.09
August.....	76.1	1.04	68.3	2.96
September.....	66.4	0.95	61.9	2.32
Average or total.....	70.6	3.81	64.4	14.44

In the course of the life-history investigations in the Grand Valley it was found that a female moth deposited as many as 316 eggs and that several laid over 300 eggs each.⁵ In other localities where the Bureau of Entomology has conducted similar investigations, the fecundity of the female moth has never been found to be so high. The nearest approach to the individual egg production in the Grand Valley was found in the Pecos Valley of New Mexico, where like climatic conditions obtain and where one female moth was recorded to have produced 259 eggs.⁶ In the fruit belt of western Michigan, where the weather conditions approximate those of western New York, the most eggs laid by a moth, according to the records of A. G. Hammar, was 161.⁷

It has been quite generally established that semiarid climatic conditions are very favorable to the development of the codling moth, whereas humid conditions and lower temperatures retard its development.

SPRAYING EXPERIMENTS IN THE GRAND VALLEY.

Spraying experiments were conducted in several orchards during the seasons of 1915, 1916, 1917, and 1918, on representative apple varieties. The results herewith presented, however, are confined to the Ben Davis and Gano, since the Grand Valley fruit growers generally experienced more difficulty in controlling the codling moth on these than on any other commercial varieties.

In the spraying experiments described an attempt was made to time the spray applications according to the development of the codling moth as indicated by the life-history studies and field obser-

⁵ Siogler, E. H., and Plank, H. K. The Life History of the Codling Moth in the Grand Valley of Colorado. U. S. Dept. Agr. Bul. 932. 1921.

⁶ Quaintance, A. L., and Geyer, E. W. Life History of the Codling Moth in the Pecos Valley, New Mexico. U. S. Dept. Agr. Bul. 429. 1917.

⁷ Hammar, A. G. Life History Studies on the Codling Moth in Michigan. U. S. Dept. Agr. Bur. Ent. Bul. 115, Pt. 1. 1912.

ventions. These studies revealed the fact that there are two full broods of larvæ and a partial third during the growing season in the Grand Valley and that these overlap to a certain extent, some larvæ hatching practically every day. In general, the hatching of each brood of larvæ begins first in small numbers, then in increasing numbers until the maximum is attained, after which there is a gradual decrease until the last larva of the brood has hatched.⁸ A tentative spraying schedule, based on certain intervals between applications, was adopted and closely adhered to throughout the work, except when it seemed advisable or became necessary to deviate therefrom.

SPRAYING EXPERIMENTS IN 1915.

The growing season of 1915 was extremely abnormal in so far as it related to the crop of apples and abundance of the codling moth. The fruit crop of the valley was practically destroyed just as the petals had dropped by the freezes of May 2, 3, and 4. Temperatures as low as 22° F. were recorded in some sections, killing apples and pears except at Palisades where peaches constitute the chief crop and in a few smudged orchards located elsewhere.

The apple orchard of Mr. Gus J. Johnson, of Highland Park, was among those that were partly saved by the timely use of oil heaters, and was available for experimental purposes. (Pl. I, fig. 1.) This orchard consisted of the Ben Davis, Jonathan, Black Twig, Winesap, and Rome Beauty varieties and was divided into 10 plats, including the unsprayed or check plat.

In Tables 2 and 3 will be found data of the experiments. Two spray poles were used, one of which was operated from the top of the spray tank and the other from the ground. Bordeaux nozzles were used for the calyx treatment except in Plat VI, and nozzles of the eddy-chamber or whirlpool-disk type were employed for all cover sprays in all of the sprayed plats except in plat VI; in this plat Vermorel nozzles were used in all applications. Plats I, II, and IX, located in different sections of the orchard, received identical treatment, a total of four cover sprays, two for the first brood and two for the second and third broods. Plats III and IV were given five cover sprays each, the former receiving three for the first brood and two for the later broods and the latter two for the first and three for the subsequent broods. Plat V was given a total of three cover sprays, two for the first brood and one for the broods that followed. Plat VI was sprayed throughout the season with a very fine mist spray delivered by Vermorel nozzles under a pressure of 90 pounds. Two cover sprays were applied for the first-brood larvæ followed by two more cover sprays for the second and third broods, making four cover treatments in all. Plats VII and VIII were given the same number of applica-

⁸ For further details see U. S. Dept. Agr. Bul. 932, *The Life History of the Codling Moth in the Grand Valley of Colorado*, by the present authors.

tions as plats I, II, VI, and IX, but in plat VII homemade arsenate of lime paste⁹ was substituted for arsenate of lead paste, and in plat VIII commercial arsenate of lime powder was used. Plat X was unsprayed for comparison with the treated plats.

TABLE 2.—*Spraying schedule for the codling moth, Johnson orchard, Grand Valley of Colorado, 1915.*

Number of plat.	Calyx spray.	Cover sprays—first brood.				Cover sprays—second and third broods.		
	A.	B.	C.	D.	E.	F.	G.	
	Petals off, May 5-7.	3 to 4 weeks after A, May 24-26.	21 to 22 days after B, June 14-15.	14 days after C, June 28.	10 to 11 weeks after A, July 16-17.	21 to 24 days after E, Aug. 6-9.	22 days after F, Aug. 28.	
I.....	First.....	Second....	Third.....		Fourth....	Fifth.....	Sixth.	
II.....	do.....	do.....	do.....		do.....	do.....		
III.....	do.....	do.....	do.....	Fourth....	Fifth.....	Sixth.....		
IV.....	do.....	do.....	do.....		Fourth....	Fifth.....		
V.....	do.....	do.....	do.....		do.....	do.....		
VI.....	do.....	do.....	do.....		do.....	Fifth.....		
VII.....	do.....	do.....	do.....		do.....	do.....		
VIII.....	do.....	do.....	do.....		do.....	do.....		
IX.....	do.....	do.....	do.....		do.....	do.....		
X.....	Check.....							

TABLE 3.—*Treatment of plats for the codling moth, Johnson orchard, Grand Valley of Colorado, 1915.*

Number of plat.	Spray materials.	Pressure.	Spraying equipment.	
			Calyx spray.	Cover sprays.
I.....	Arsenate of lead, paste, 2 pounds—50...	Pounds. 200-225	Bordeaux nozzles.	Whirlpool-disk nozzles.
II.....	do.....	200-225	do.....	Do.
III.....	do.....	200-225	do.....	Do.
IV.....	do.....	200-225	do.....	Do.
V.....	do.....	200-225	do.....	Do.
VI.....	do.....	90	Vermorel nozzles.	Vermorel nozzles.
VII.....	Arsenate of lime, homemade, 2 pounds—50.	200-225	Bordeaux nozzles.	Whirlpool-disk nozzles.
VIII.....	Arsenate of lime, commercial powder, $\frac{1}{2}$ pound—50.	200-225	do.....	Do.
IX.....	Arsenate of lead, paste, 2 pounds—50.	200-225	do.....	Do.
X.....	Check—unsprayed.			

The results of these experiments will be found in Table 4, by reference to which it will be seen that plats I, II, and IX, the treatments of which were alike, produced from 52.88 to 68.41 per cent of fruit free from worms. Under the varying conditions that exist in most orchards, such as unevenness of insect infestation, likelihood of moth migration, differences among the trees in the crop yield, and other contributing factors, uniform results can not always be obtained. Because of these conditions in commercial orchards one section frequently is wormier than another, although the treatment is uniform

⁹ For method of preparation see U. S. Dept. Agr. Bul. 278, Miscellaneous Insecticide Investigations, by E. W. Scott and E. H. Siegler.

throughout the orchard. Plat III, in which three cover applications were made for the first brood and two for the later broods, produced the best crop of apples from the point of insect control, 72.22 per cent of the fruit being free from worms. Plat IV was treated with the same number of cover sprays as plat III, but the number of applications for the broods was reversed, and with this treatment 66.48 per cent of the fruit was free from worm infestation. In plat V only three cover sprays were applied, and the treatment resulted in 62.21 per cent of uninfested fruit. As previously noted, plat VI was sprayed five times by means of Vermorel nozzles with a pressure of but 90 pounds, producing a very fine mistlike spray. Generally speaking the results indicate that this treatment was as effective as the other methods employed, there being 63.78 per cent of worm-free fruit. The low-pressure mist spray also gave as good results as the high-pressure coarse sprays in preventing the entrance of larvæ through the calyx end of the apple. It should be borne in mind, however, that in commercial spraying a reasonably high pressure of 200 to 250 pounds will increase the speed of the work and that the distribution of the spray material is likely to be more thorough than when applied under a low pressure.

Arsenate of lime, both homemade and commercial, as used in plats VII and VIII, gave comparatively poor results.

The unsprayed or check trees, plat X, were very wormy, giving but 13.51 per cent of fruit free from larvæ.

The sprayed fruit was well protected against the calyx entrance worms except in plat VIII. With this exception, the percentage of wormy apples infested at the calyx in the sprayed plats varied from 3.72 to 5.92. The unsprayed plat produced 55.06 per cent of wormy fruit infested at the calyx.

TABLE 4.—*Summary of results of spraying for the codling moth, Johnson orchard, Grand Valley of Colorado, 1915.*

Plat.	Number of trees examined.	Total number of apples examined.	Total number of worms (including extra).	Average number of worms for all apples.	Average number of worms for wormy apples.	Per cent of worms (including extra) entering apples.			Per cent of wormy apples infested.			Total number of stings.	Average number of stings for all apples.	Per cent of worm-free apples free from stings.	Per cent of all apples free from worms
						At calyx.	At side.	At stem.	At calyx.	At side.	At stem.				
I.....	5	4,208	2,952	0.70	1.59	2.34	97.43	0.24	3.72	95.91	0.38	5,306	1.26	40.54	55.87
II.....	12	9,356	7,347	.79	1.67	3.17	96.49	.34	5.29	94.38	.34	17,873	1.91	33.56	52.88
III.....	2	2,192	844	.39	1.39	3.44	96.09	.47	4.76	94.58	.66	2,067	.94	52.12	72.22
IV.....	5	3,174	1,523	.48	1.43	4.14	95.40	.46	5.92	93.52	.56	2,131	.99	44.27	66.48
V.....	7	6,005	3,567	.59	1.57	2.75	96.92	.34	4.32	95.24	.44	5,549	.92	53.51	62.21
VI.....	7	3,708	2,013	.54	1.50	3.87	95.83	.30	5.81	93.89	.30	3,450	.93	48.50	63.78
VII.....	4	1,755	2,182	1.22	1.86	2.38	97.25	.37	4.42	95.15	.43	2,098	1.18	56.49	34.17
VIII.....	3	1,601	2,308	1.44	2.00	6.50	93.15	.35	12.98	86.76	.26	1,320	.82	52.36	27.80
IX.....	10	7,613	3,438	1.45	1.43	3.72	95.75	.52	5.32	94.18	1.50	3,337	.96	49.39	68.41
X.....	3	2,820	5,077	1.80	2.08	26.45	72.31	1.24	55.06	43.87	1.07	333	.12	90.03	13.51

In the treated plats over 90 per cent of the worms actually infesting the fruit gained entrance through the side of the apple and less than 7 per cent entered by way of the calyx. In untreated plat X 72.31 per cent of the larvæ entered through the side of the fruit and 26.45 per cent through the calyx end. It will thus be seen from these data that one of the chief difficulties in controlling the codling moth in the Grand Valley of Colorado is to prevent the larvæ from entering the apple through the side.

In the plats where arsenate of lead was employed the average number of larvæ for worm-infested fruit varied from 1.39 to 1.67, whereas in the arsenate of lime plats this average was increased to 1.86 and 2, and in the unsprayed plat there was a further increase to 2.08 larvæ for each wormy apple. The higher the percentage of apples free from worms the lower the average number of worms per apple. Thus in plat III, where the best control was obtained and where 72.22 per cent of apples were free from worms, there was an average of only 0.39 larva per apple, and in plat X, which was unsprayed and yielded but 13.51 per cent of worm-free fruit, there were 1.80 larvæ per apple.

In scoring results, account was taken of the so-called codling moth "sting" (Pl. II). The sting is a shallow excavation extending through the skin of the apple into the flesh to a depth of about one-sixteenth to three thirty-seconds of an inch. It is caused by newly hatched larvæ that only succeed in eating their way through the skin before succumbing to the poison, or, for other reasons, do not penetrate deeper into the fruit. In the sprayed plats the average number of stings per apple varied from 0.82 to 1.91, whereas in the unsprayed plat the average was only 0.12.

It is the belief of the writers that, with a uniform infestation and crop and with other factors equal, the number of stings is directly proportional to the number of worm-free apples. In other words, if the spray treatment is effective, the only indication of worm attack will be found in the sting marks, and these will increase within certain limits as the number of worm-free apples increases. In the case of unsprayed fruit, the worms are not subjected to a poison, and hence what might result in only a sting in a sprayed apple becomes a worm hole in the untreated fruit. It should not be inferred, however, that unsprayed fruit is totally devoid of stings, for sting marks sometimes occur on untreated fruit and may be accounted for by larvæ which start an entrance hole and then change to another place, or by larvæ that, before penetrating very far into the fruit, are blown off by wind, brushed off by foliage, or washed off by heavy rains.

SPRAYING EXPERIMENTS IN 1916.

In 1916 the Gus J. Johnson orchard, at Highland Park, and the J. D. Nettleton orchard, at Fruitvale, were used for experimental purposes.

In the Johnson orchard the principal part of the experimental work was a test of the efficiency of coarse sprays applied with a short rod and Bordeaux nozzle in comparison with mist sprays applied by means of spray poles equipped with whirlpool-disk nozzles.

The short rod referred to consisted of a piece of iron pipe about 1 foot in length, to one end of which was attached a Bordeaux nozzle and to the other a cut-off to which the hose was connected. Under a pressure of 225 to 250 pounds and with the nozzle sufficiently open, the spray was practically a solid stream as it left the nozzle, but broke up more or less as it reached the tree. This type of spraying apparatus had been used by many Grand Valley growers for several seasons in preference to the spray poles, formerly employed, because it rendered spraying less burdensome and increased the speed of the work. The spray gun, which was subsequently developed, is an improvement over the short rod, in that the character of the spray can be readily graduated from fine to coarse.

The spray history of the experiments in the Johnson orchard will be found in Tables 5 and 6.

TABLE 5.—*Spraying schedule for the codling moth, Johnson orchard, Grand Valley of Colorado, 1916.*

Number of plat.	Calyx spray.	Cover sprays—first brood.				Cover sprays—second and third broods.	
	A.	B.	C.	D.	E.	F.	G.
	Petals off, May 2-3.	3 to 4 weeks after A, May 29.	14 days after B, June 12.	18 days after B, June 16.	14 days after C, June 26.	9 to 10 weeks after A, July 8.	34 to 41 days after F, Aug. 11-18.
I.....	First.....	Second.....	Third.....		Fourth.....	Fifth.....	Sixth.....
II.....	do.....	do.....	do.....			do.....	Do.....
III.....	do.....	do.....		Third.....		Fourth.....	Fifth.....
IV.....	do.....	do.....		do.....		do.....	Do.....
V.....	do.....	do.....				Third.....	Fourth.....
VI.....	do.....	do.....				do.....	Do.....
VII.....	Check.....	do.....					

TABLE 6.—*Treatment of plats for the codling moth, Johnson orchard, Grand Valley of Colorado, 1916.*

Number of plat.	Spraying materials.	Spraying equipment.	
		Calyx spray.	Cover sprays.
I.....	Arsenate of lead, powder, 1 pound—50.	Spray poles and Bordeaux nozzles.	Spray poles and whirlpool-disk nozzles.
II.....	do.....	Short rod and Bordeaux nozzle.	Short rod and Bordeaux nozzle.
III.....	do.....	Spray poles and Bordeaux nozzles.	Spray poles and whirlpool-disk nozzles.
IV.....	do.....	Short rod and Bordeaux nozzle.	Short rod and Bordeaux nozzle.
V.....	do.....	Spray poles and Bordeaux nozzles.	Spray poles and whirlpool-disk nozzles.
VI.....	do.....	Short rod and Bordeaux nozzle.	Short rod and Bordeaux nozzle.
VII.....	Check—unsprayed.....		



FIG. 1.—THE JOHNSON EXPERIMENTAL ORCHARD.



FIG. 2.—APPLE INFESTED BY THE CODLING MOTH, THE YOUNG LARVA
HAVING ENTERED FROM THE SIDE.

CONTROL OF THE CODLING MOTH IN THE GRAND VALLEY
OF COLORADO.



FIG. 1.—CODLING MOTH "STING" ON SIDE OF APPLE.
NATURAL SIZE.



FIG. 2.—VERTICAL SECTION THROUGH A CODLING MOTH "STING."
ENLARGED.

CONTROL OF THE CODLING MOTH IN THE GRAND
VALLEY OF COLORADO.

By reference to Table 7 it will be noted that in each instance the coarse sprays, as applied with the short rod and Bordeaux nozzle, gave control inferior to that on the plats treated with the poles and whirlpool-disk nozzles. Thus, plat I, fine spray, yielded 89.48 per cent of fruit free from worms in comparison with 79.54 per cent in plat II, which was treated with the coarse spray. In plat III, sprayed with the disk nozzles, there was 85.05 per cent of uninfested fruit, whereas in plat IV, treated by means of the Bordeaux nozzle, there was but 71.06 per cent of fruit free from worms. Again, in plat V, which was treated with the fine spray, there was 89.70 per cent of worm-free fruit in comparison with 81.43 per cent in plat VI, which was sprayed with the Bordeaux nozzle. The untreated plat, plat VII, produced 30.98 per cent of fruit free from worms.

It is the belief of the writers that the coarse sprays do not adhere so readily to the fruit, especially to the waxy skin of apples of the Ben Davis type, as do the fine mist sprays. It is believed further that the distribution of the poison is more thorough with the spray poles and disk nozzles than with the short rod and Bordeaux nozzle.

The results of this experiment considered as a whole seem to show that three cover sprays were more efficient than five. But this anomaly may perhaps be accounted for by the fact that there was no fruit in plats V and VI the preceding year, it having been destroyed by the spring freezes; hence, there being no overwintering larvæ on these trees, the infestation came solely from moths that migrated from other trees.

A further study of Table 7 will show, as in the experiments of 1915 (Table 4), that the average number of worms per apple was lowest where the best control was obtained, with a range in this respect among the sprayed plats of from 0.14 to 0.40. In the unsprayed plat there was an average of 1.43 worms per apple. The spray material readily checked the worms from gaining entrance through the calyx, over 90 per cent of the larvæ having entered the fruit through the side. In the sprayed plats from 2 to 9.99 per cent of the wormy fruit was infested at the calyx while in the unsprayed plat 28.43 per cent of the wormy fruit was caused by larvæ that entered by way of the calyx.

The average number of stings in the sprayed plats for all apples varied from 0.34 to 0.82 and in the unsprayed plat the average number was 0.23.

TABLE 7.—*Summary of results of spraying for the codling moth, Johnson orchard, Grand Valley of Colorado, 1916.*

Plat.	Num-ber of trees ex-amin- ed.	Total num-ber of worms (includ- ing extra).	Aver- age num- ber of worms for all apples.	Aver- age num- ber of worms for wormy apples.	Per cent of worms (in- cluding extra) enter- ing apples.			Per cent of wormy apples infested.			Total num- ber of stings.	Aver- age num- ber of stings for all apples.	Aver- age num- ber of stings for stung apples.	Per cent of wormy apples free from sting	Per cent of worm- free apples free from stings.	Per cent of all apples free from worms.	Per cent of all apples free from worms and stings.	Per cent of all apples free from worms and stings.
					At calyx.	At side.	At stem.	At calyx.	At side.	At stem.								
I.....	10	12,156	1,705	1.33	3.16	95.85	0.99	4.22	94.61	1.17	6,384	1.72	57.78	70.82	89.48	69.43	63.35	
II.....	5	6,066	1,601	1.29	7.74	91.07	1.19	9.99	88.56	1.45	3,572	1.69	63.42	65.60	79.54	65.15	52.18	
III.....	10	12,196	2,386	1.31	1.60	97.53	.88	2.08	96.76	1.16	6,873	1.70	56.56	68.70	85.05	66.88	58.43	
IV.....	5	4,253	1,693	1.38	2.60	96.69	.71	3.57	95.45	.98	3,497	1.91	56.16	57.74	71.06	57.00	41.03	
V.....	10	16,014	2,209	1.34	1.49	97.74	.77	2.00	97.03	.97	5,439	1.50	63.13	79.07	89.70	77.43	70.93	
VI.....	5	3,700	898	1.31	2.23	97.21	.56	2.91	96.36	.73	1,929	1.60	63.90	68.27	81.43	67.46	55.59	
VII.....	4	3,954	5,669	1.43	13.69	85.52	.79	28.43	70.87	.70	1,905	1.32	78.78	91.10	30.98	82.60	28.22	

A series of experiments was conducted in the Nettleton orchard, but the results were largely vitiated by frosts during May shortly after the setting of the fruit. As a consequence of the low temperatures, small frost pits or cracks in the epidermis developed in much of the fruit, particularly around the calyx end of the apple. It was practically impossible to force the spray material into these pits which thus served as an ideal place of entrance for the worms. Since the frosted fruit was unevenly distributed in the several plats, there was no fair basis on which to draw a comparison of the value of the different treatments.

SPRAYING EXPERIMENTS IN 1917.

The major part of the experimental spray work during the season of 1917 was done in the orchard of the George Smith estate, at Orchard Mesa. This orchard consisted of approximately 20 acres of Ben Davis apple trees about 20 years of age and of fairly uniform size and vigor. The orchard was divided into 17 blocks, or plats, all of which were treated, except the two check plats XVI and XVII, located in diagonally opposite corners of the orchard. The treatment of the several plats and the schedule of applications are presented in Tables 8 and 9.

A power sprayer delivering about 225 pounds pressure was employed in all of the liquid-sprayed plats, and a power dusting machine was used in the three dust-treated plats. With the exception of plats XIV and XV, which were sprayed by the owner, all of the plats were cared for by the experimental force. In the first or calyx treatment the sprayed plats were sprayed by means of two spray poles, equipped with Bordeaux nozzles, one of which was operated from the spray tower and the other from the ground. In applying the cover sprays, the Bordeaux nozzles were replaced by the whirlpool-disk type nozzles, except in plats XIV and XV, which were treated by the owner. In plat XIV the use of the Bordeaux nozzles was continued, for the cover applications, throughout the season; in plat XV a spray gun, operated from the ground, was employed for all cover sprays.

TABLE 8.—*Spraying schedule for codling moth, Smith orchard, Grand Valley of Colorado, 1917.*

Number of plat.	Calyx spray.	Cover sprays, first brood.				Cover sprays, second and third broods.			
	A.	B.	C.	D.	E.	F.	G.	H.	I.
	Petals off May 24-29.	19 to 22 days after A, June 12-15.	11 to 13 days after B, June 23-25.	16 days after B, June 28.	10 to 13 days after C, July 3-6.	8 weeks after A, July 15-20.	27 days after F, Aug. 14.	36 days after F, Aug. 23-25.	21 days after G, Sept. 4.
I.....	First.....	Second..	Third...		Fourth..	Fifth....		Sixth..	Sev-enth.
II.....	do.....	do.....	do.....	.....	do.....	do.....	.....	do.....	
III.....	do.....	do.....	do.....	.....	do.....	do.....	.....	do.....	
IV.....	do.....	do.....	do.....	.....	do.....	do.....	.....	do.....	
V.....	do.....	do.....	.....	Third...	Fourth..	Fourth..	.....	Fifth..	
VI.....	do.....	do.....	Third...	.....	Fourth..	Fifth....	.....	Sixth..	
VII.....	do.....	do.....	do.....	.....	do.....	do.....	.....	do.....	
VIII.....	do.....	do.....	.....	Third...	Fourth..	Fourth..	.....	Fifth..	
IX.....	do.....	do.....	Third...	.....	Fourth..	Fifth....	Sixth..	.....	
X.....	Calyx spray omitted.	First....	Second..	.....	Third....	Fourth..	.....	Fifth..	
XI.....	First....	Second..	Third....	.....	Fourth..	Fifth....	.....	Sixth..	
XII.....	do.....	do.....	do.....	.....	do.....	do.....	.....	do.....	
XIII.....	do.....	do.....	do.....	.....	do.....	do.....	.....	do.....	
XIV.....	do.....	do.....	do.....	.....	do.....	do.....	.....	do.....	
XV.....	do.....	do.....	do.....	.....	do.....	do.....	.....	do.....	
XVI.....	Check—un-sprayed.	.....	.....	.....	.....	.....	.....	.....	
XVII.....	do.....	.....	.....	.....	.....	.....	.....	.....	

TABLE 9.—*Treatment of plats for codling moth, Smith orchard, Grand Junction, Colo., 1917.*

Number of plat.	Spray materials and supplemental control measures.	Spraying and dusting equipment.	
		Calyx spray.	Cover sprays.
I.....	Arsenate of lead, powder, 1 pound—50, and codling moth traps.	Spray poles and Bordeaux nozzles.	Spray poles and whirlpool-disk nozzles.
II.....	Arsenate of lead, powder, 1 pound—50.	do.....	Do.
III.....	Nicotine sulphate, 40 per cent, $\frac{1}{2}$ pint—50.	do.....	Do.
IV.....	Arsenate of lead, powder, 1 pound—50, and nicotine sulphate, 40 per cent, $\frac{1}{2}$ pint—50.	do.....	Do.
V.....	Arsenate of lead, powder, 1 pound—50, and codling moth traps.	do.....	Do.
VI.....	Arsenate of lead, powder, 1 pound—50, and fish-oil soap, 2 pounds—50.	do.....	Do.
VII.....	Arsenate of lime, powder, $\frac{3}{4}$ pound—50.	do.....	Do.
VIII.....	Arsenate of lead, powder, 1 pound—50.	do.....	Do.
IX.....	do.....	do.....	Do.
X.....	do.....	Calyx spray omitted.	Do.
XI.....	Arsenate of lead, 20 per cent, and hydrated lime, 80 per cent.	Power dusting machine.	Power dusting machine.
XII.....	Arsenate of lead, 15 per cent, and hydrated lime, 85 per cent.	do.....	Do.
XIII.....	Arsenate of lead, 10 per cent, and hydrated lime, 90 per cent.	do.....	Do.
XIV.....	Arsenate of lead, powder, 1 pound—50.	Spray poles and Bordeaux nozzles.	Spray poles and Bordeaux nozzles.
XV.....	do.....	do.....	Spray gun.
XVI.....	Check—unsprayed.	.....	.....
XVII.....	do.....	.....	.....

All the plats, except the unsprayed checks and plat X, were given the calyx treatment. The total number of applications varied from five to seven, with six in the majority. Plats I, II, III, and IV were given the same number of applications, three cover sprays for the first brood and two for the second and third broods. Plats V and VIII had but four cover sprays of lead arsenate, two for the first brood and two for the later broods, and in addition plat V was provided with the codling-moth trap applied to each tree. Plats VI and VII were sprayed throughout the season at the same time as plats I to IV, but, as described later, received different treatment. Plat IX received the largest number of applications, three cover sprays for the first brood and the same number for the second and third broods, making a total of six cover treatments. Plat X was given five cover sprays, but, as previously mentioned, the calyx treatment was omitted. Plats XI, XII, and XIII were given treatment at the same time as the other plats having five cover applications, but the dusting method was substituted for the liquid.

Arsenate of lead, powder, at the rate of 1 pound to 50 gallons of water was used in all of the sprayed plats, except plat VII, in which arsenate of lime, powder, three-fourths pound to 50 gallons, was employed, and plat III, where 40 per cent nicotine sulphate, diluted 1 part in 800 parts of water, was used. Forty per cent nicotine sulphate at this strength was also used with arsenate of lead in plat IV, and in plat VI fish-oil soap, 2 pounds to 50 gallons, was used as a spreader and sticker. Codling-moth traps, described on pages 35-38, were used in plats I and V. Plats XI, XII, and XIII were dusted with arsenate of lead mixed with hydrated lime as a filler in the proportions shown in Table 9. In plat XI a dust mixture containing 20 per cent of arsenate of lead and 80 per cent of hydrated lime was used; in plat XII, the arsenate of lead was decreased to 15 per cent and the hydrated lime increased to 85 per cent. Plat XIII was treated with 10 per cent of arsenate of lead and 90 per cent of hydrated lime. Plats XIV and XV were sprayed by the owner with arsenate of lead and, as previously stated, plats XVI and XVII were untreated throughout the season.

The summary of results of these experiments is presented in Table 10.

Plat VI, which was sprayed six times with arsenate of lead and fish-oil soap, yielded 78.06 per cent of apples free from worms, which was the highest percentage of uninfested fruit in the orchard. Also the average number of worms for all apples was as low in this plat as in any other. The percentage of all apples free from worms and stings in plat VI was 46.22, which was not as high as that obtaining in plats IX (46.44 per cent), V (47.84 per cent), and IV (49.82 per cent). Plat IX produced the next best results, 76.53 per cent of all the fruit being free from worms as a result of seven applications of arsenate of lead; plat V, with five treatments supplemented with the codling-moth trap, yielded 72.29 per cent of uninfested fruit; plat IV, 72.05 per cent, with six applications of arsenate of lead and nicotine sulphate. Two other plats, I and VIII, produced 70.99 and 73.49 per cent of worm-free fruit, respectively; the former being sprayed six times with arsenate of lead, supplemented with the codling-moth trap, and the latter having only five applications of arsenate of lead. Plat II, which received six applications of arsenate of lead, yielded but 62.10 per cent of worm-free fruit, and but 27.04 per cent of fruit free from worms and stings. Apparently the infestation in this plat was somewhat heavier than that which prevailed in some of the other plats. Plat III was treated six times with nicotine sulphate, which resulted in but 37.97 per cent of fruit free from worms. The percentage of this fruit free from stings was relatively high (88.62 per cent), a condition which would naturally be expected, owing to the fact that the majority of the larvæ that attacked the fruit were able to enter it without being killed by the spray. Attention is called to the fact that in this plat (plat III) 18.07 per cent of all the worms infesting the apples entered by way of the calyx end and that 22.39 per cent of the wormy apples were infested at the calyx. In plat VII arsenate of lime was used with unsatisfactory results, there being 36.51 per cent of worm-free apples and only 20.33 per cent of the fruit free from worms and stings. Plat X was sprayed at the same time as the plats that had six treatments, except that the calyx application was omitted, thus making a total of five treatments. The percentage of worm-free fruit was 46.33, and the percentage of all apples free from worms and stings was 25.36. It is worthy of note that the percentage of worms entering the calyx was high (29.83 per cent), and that 37.42 per cent of the wormy apples were infested at the calyx.

Plats XI, XII, and XIII were dusted six times with mixtures containing 20, 15, and 10 per cent of arsenate of lead, respectively. The results of these treatments indicate quite conclusively that dusting is unsatisfactory for the control of the codling moth in the Grand Valley. With as much as a 20 per cent lead arsenate mixture only 40.75 per cent of the fruit was free from worms; with a 15 per cent lead arsenate mixture there was 34.58 per cent of worm-free fruit;

and with a mixture containing 10 per cent of lead arsenate there was only 14.38 per cent of uninfested fruit, all of which would indicate practically no control. Furthermore, the dust was not nearly so effective as the liquid sprays in preventing the entrance of worms at the calyx.

The two plats sprayed by the grower, plats XIV and XV, produced a lower percentage of control than those treated by the experimental staff. Plat XIV, in which spray poles and Bordeaux nozzles were used throughout the season, yielded 40.21 per cent of uninfested fruit, whereas plat XV, in which the spray gun was employed for the cover sprays, gave but 30.22 per cent of worm-free fruit.

The abundance of the codling moth in this orchard is indicated in plats XVI and XVII, both of which were untreated and which produced but 8.83 and 8.54 per cent of worm-free fruit. The number of stings in these plats, as was to be expected, was not large, there being 88.16 per cent of fruit free from stings in plat XVI and 87.42 per cent in plat XVII. It will be further noted that in these plats the percentage of calyx worms was large, 30.26 and 28.92 per cent, respectively, with 47.09 and 47.50 per cent of the wormy apples infested at the calyx end.

CODLING-MOTH TRAP EXPERIMENTS IN 1917.

A section of the J. B. Hunter orchard near Fruita, Colo., consisting of Ben Davis and Gano apple trees, was divided into three plats. Plat I, containing 60 trees, was banded and sprayed; plat II, having 108 trees, was provided with the codling-moth trap and sprayed; while plat III, 99 trees, received no other treatment than five spray applications as described below.

The spray applications, five in all, were made by the grower on all the plats as follows: Calyx spray applied June 1-2; first cover spray June 14-16; second cover spray July 11; third cover spray July 27; fourth cover spray August 16. A power sprayer was used throughout the season and this was equipped with Bordeaux nozzles for the calyx application and whirlpool-disk type nozzles having a large aperture disk for all of the cover treatments.

The data obtained from the examination of the dropped and harvested fruit from eight trees in each plat will be found in Table 11. It will be noted therein that plat III, which had only the spray treatment, produced 76.56 per cent of fruit free from worms, a higher percentage than that of plats I and II, which received theoretically better treatments. There is no logical explanation for these results other than the possibility of unevenness of infestation and yield of fruit.

TABLE 11.—Summary of results of spraying for the codling moth, Hunter orchard, Grand Valley of Colorado, 1917.

Plat.	Num- ber of trees ex- amined.	Total num- ber of apples ex- amined.	Total num- ber of worms (includ- ing extra).	Aver- age num- ber of worms for all apples.	Percentage of worms (including extra) en- tering apples.			Percentage of wormy apples infested.			Total num- ber of stings.	Aver- age num- ber of stings for all apples.	Aver- age num- ber of stings for free from stings.	Per- cent- age of wormy apples free from stings.	Per- cent- age of all apples free from worms, and stings.	Per- cent- age of all apples free from worms, and stings.	Per- centage of all apples free from worms, and stings.
					Percentage of worms (including extra) en- tering apples.			Percentage of wormy apples infested.									
					At calyx	At side.	At stem.	At calyx.	At side.	At stem.							
I.	8	24,345	13,446	0.55	16.91	81.91	1.18	21.95	77.01	1.04	15,287	1.59	57.98	62.76	57.44	60.72	36.04
II.	8	38,781	15,209	.39	30.43	68.10	1.47	33.79	59.06	1.15	12,942	.33	74.73	76.13	70.00	75.71	53.29
III.	8	45,089	14,056	.31	22.52	75.52	1.66	28.57	68.81	1.62	15,812	.35	71.19	76.09	76.56	74.95	58.26

NOTE.—See p. 16 for treatments.

TABLE 12.—Collections of codling moth larvae and pupæ from banded trees, Plat I, Hunter orchard, Grand Valley of Colorado, 1917.

Tree No.	Date of collection.																Nov. 21, larvæ.
	July 3.		July 12.		July 18.		July 28.		Aug. 7.		Aug. 17.		Aug. 27.		Sept. 6.		
	Larvæ.	Pupæ.	Larvæ.	Pupæ.	Larvæ.	Pupæ.	Larvæ.	Pupæ.	Larvæ.	Pupæ.	Larvæ.	Pupæ.	Larvæ.	Pupæ.	Larvæ.	Pupæ.	
1	6		21	7	21		17	7	10	5	10		20		13		44
2	12		31	7	14		20	8	6	5	11		10		9		48
3	58		55	17	27	3	33	5	10	2	20		10		14		67
4	11	1	26	6	17	1	18	7	2	1	3		11		20		34
5	5		26	3			13	7	6				9		19		37
6	1		29	3			4	3	19	2	11		6		8		28
7	3	1	12	3	18	2	4	8	6	2	7		4		8		27
8	2		10		9		13	8	6	6	5		4		5		26
9	2		22	14	30	3	8	6	8	6	16		7		24		27
10	12		10	2	21	1	37	6	15	12	32		14		13		47
11	7		10	4	11	2	21	8	9	3	28		11		37		38
12	13		18	12	31	4	12	3	9	7	18		4		4		16
13	5		27	4	36	5	25	8	6	4	8		8		9		26
14			18	2	6		14	9	12	6	12		3		15		25
15		1	8	3			10	7	3	4	3		4		16		36
16		1	6	3	27	2	10	8	6	5	10		8		7	2	25
17			12		12	2	6	4	8	8	9		1		4		16

[illegible]

TABLE 13.—Collections from codling moth traps, Plat II, Hunter orchard, Grand Valley of Colorado, 1917.

Tree No.	Date of collection.															
	July 12.		July 18.		July 23.		Aug. 7.		Aug. 17.		Aug. 27.		Sept. 6.		Nov. 21, larvæ.	
	Larvæ.	Pupæ.	Larvæ.	Pupæ.	Larvæ.	Pupæ.	Larvæ.	Pupæ.	Larvæ.	Pupæ.	Larvæ.	Pupæ.	Larvæ.	Pupæ.		
1	15	12	24	2	16	31	12	3	5	2	15	8	19	1	65	
2	27	6	25	4	17	17	11	4	15	2	24	1	43	1	84	
3	33	21	26	5	27	6	6	8	11	6	18	9	20	2	123	
4	10	17	18	5	13	14	10	10	5	2	9	24	42	2	121	
5	36	5	30	5	15	14	10	5	12	6	24	1	20	1	75	
6	9	3	15	5	15	20	5	2	10	1	19	15	13	19	18	
7	25	2	19	5	20	22	10	7	10	1	3	19	19	19	73	
8	24	6	19	3	6	21	8	4	3	1	9	36	33	33	90	
9	11	7	11	1	13	10	3	4	4	1	21	17	28	1	90	
10	9	1	14	1	15	15	6	6	10	2	10	20	20	20	47	
11	16	3	27	7	14	16	5	2	5	2	10	6	19	6	47	
12	9	5	27	1	17	14	5	2	8	2	15	19	19	19	61	
13	17	12	25	4	20	21	9	9	6	2	10	22	22	22	71	
14	14	20	21	3	10	20	12	4	7	3	14	4	15	15	51	
15	15	13	28	3	5	9	5	3	5	3	5	5	7	7	29	
16	2	6	6	3	10	9	5	5	4	1	5	5	7	5	31	
17	6	7	10	2	7	8	5	5	7	4	5	5	16	16	74	
18	3	3	17	1	15	21	11	7	17	1	15	8	10	10	44	
19	11	2	15	2	22	21	7	7	7	1	8	10	10	10	44	
20	7	3	6	2	12	24	7	3	7	1	8	10	10	10	44	
Total number larvæ for season..... 3,252																Total number all stages for season..... 3,941
Total number pupæ for season..... 687																Average number all stages per tree..... 197.05
Total number moths for season..... 2																

Total number larvæ for season.....	3,252	Total number all stages for season.....	3,941
	607	Average number all stages per tree.....	197.05

In Tables 12 and 13 will be seen the data obtained from examinations of the bands and traps. From 56 banded trees 8,805 larvæ and pupæ, or an average of 157.23, were taken, and from 20 codling-moth traps 3,941 larvæ, pupæ, and moths, or an average of 197.05, were secured. The destruction of so large a number of individuals should aid gradually in obtaining better control despite the fact that the experimental data for this, the first year, indicate otherwise.

Part of the orchard of Charles Lamb near Highland Park was also used for the codling-moth trap experiments. This was sprayed by the grower who used the short rod equipped with a Bordeaux type of nozzle in making all the spray applications. In addition to the calyx treatment, six cover sprays were applied. Plat I was sprayed and trapped, plat II was sprayed, and plat III was untreated.

The results of the fruit examinations of eight trees in each of plats I and II and four trees in plat III are given in Table 14. In plat I, which was sprayed and trapped, 50.54 per cent of the dropped and harvested fruit was free from worm infestation; whereas in plat II, which was merely sprayed, there was 64.54 per cent of uninfested fruit. The unsprayed plat produced 11.45 per cent of fruit free from larvæ.

It will be noted in Table 15 that 5,512 larvæ, pupæ, and moths were collected from 20 codling-moth traps and that the average per trap was 275.6.

In the Smith experimental orchard, where the principal spraying experiments of 1917 were conducted, examinations were made of 20 codling-moth traps in plat I and of 15 in plat V. The results are presented in Tables 16 and 17, in which it will be seen that in plat I, 6,186 larvæ, pupæ, and moths, or an average of 309.3 per trap, were secured, while in plat V a total of 4,673 or an average per trap of 311.53 individuals were captured.

TABLE 14.—*Summary of results of spraying for the codling moth, Lamb orchard, Grand Valley of Colorado, 1917.*

Plat.	Num- ber of trees ex- amined.	Total num- ber of apples ex- amined.	Total num- ber of worms (includ- ing extra).	Aver- age num- ber of worms for all apples.	Percentage of worms (including extra) en- tering apples.			Percentage of wormy apples infested.			Total num- ber of stings.	Aver- age num- ber of stings for all apples.	Aver- age num- ber of stings for stung apples.	Per- centage of wormy apples free from stings.	Per- centage of all apples free from worms and stings.	Per- centage of all apples free from stings.	Per- centage of all apples free from worms and stings.
					At calyx.	At side.	At stem.	At calyx.	At side.	At stem.							
I.	8	15,380	9,544	1.25	3.51	95.32	1.17	4.40	94.35	1.25	10,672	1.59	66.63	46.82	50.54	56.62	23.69
II.	8	20,578	8,366	1.17	5.27	93.12	1.61	6.21	92.21	1.58	14,003	1.72	67.90	56.21	64.54	60.35	36.28
III.	4	8,949	11,752	1.48	24.99	73.69	1.32	37.11	61.56	1.33	1,381	1.23	87.57	86.15	11.45	87.42	9.87

NOTE.—See page 21 for treatments.

TABLE 15.—*Collections from codling moth traps, plat I, Lamb orchard, Grand Valley of Colorado, 1917.*

Tree No.	Date of collection.											
	July 6.		July 16.		July 26.		Aug. 5.		Aug. 15.		Aug. 25.	
	Larvæ.	Pupæ.	Larvæ.	Pupæ.	Larvæ.	Pupæ.	Larvæ.	Pupæ.	Larvæ.	Pupæ.	Larvæ.	Pupæ.
1.	4	1	36	34	24	38	10	19	1	1	12	14
2.	9	1	20	49	15	27	12	17	1	1	11	25
3.	31	2	26	40	13	11	17	11	3	3	27	23
4.	24	4	34	34	11	23	18	17	5	5	15	33
5.	29	4	43	60	23	31	5	13	5	1	1	2
6.	11	19	11	19	31	27	18	16	3	1	1	1
7.	13	1	21	40	13	24	18	13	4	1	1	4
8.	13	1	17	28	11	31	15	11	8	3	1	18
9.	27	5	19	52	18	33	2	8	6	1	1	26
10.	12	2	21	62	4	23	8	13	4	3	19	34
11.	9	4	4	18	6	6	3	8	2	3	20	35
12.	9	5	29	38	26	9	6	2	1	2	15	27
13.	5	5	24	20	9	11	6	5	5	3	9	11
14.	9	9	37	30	37	38	14	17	4	3	8	32
15.	9	3	31	39	28	49	10	19	4	3	14	37
16.	9	2	18	37	14	14	16	11	4	3	18	27
17.	12	3	12	22	14	15	6	10	2	1	15	18
18.	7	3	3	15	6	12	6	6	14	3	19	22
19.	11	3	20	32	9	16	9	16	1	3	20	48
20.	21	4	28	40	15	31	9	10	1	1	34	48
Total number larvæ for season.	3,962											5,512
Total number pupæ for season.	1,542											275.6
Total number moths for season.	8											

Total number all stages for season..... 5,512
 Average number all stages per tree..... 275.6

As will be noted in Table 10, plat I yielded 70.99 per cent of fruit free from worms, an improvement in favor of the traps over plat II, which was untrapped but received the same number of spray applications (six in all) and which yielded 62.1 per cent of worm-free fruit. On the other hand, the traps did not improve the results in plat V, which, like plat VIII, received a total of five applications, the yield of worm-free fruit in these two plats being 72.29 per cent and 73.49 per cent, respectively.

From the foregoing experiments it will be seen that the traps captured an average of from 197.05 to 311.53 individuals per tree; but contrary to what might be expected, the reduction in the number of insects was not generally followed by a corresponding decrease in the percentage of wormy fruit. This would appear illogical, and it will therefore be necessary to make further tests covering a longer period of time before the value of the codling-moth traps as a supplementary control measure can be determined.

SPRAYING EXPERIMENTS IN 1918.

The spraying experiments in 1918 were conducted in the Red Cross orchard on a block of Gano trees about 13 years of age. These trees were subdivided into 12 plats, of which 10 were sprayed and the remaining 2 were untreated checks located in diagonally opposite corners of the orchard.

Table 18 shows the treatment given in the different plats. Arsenate of lead, powder, at the rate of 1 pound to 50 gallons was used in all of the sprayed plats, except in plats IX and X where the strength was reduced to one-half pound to 50 gallons. Fish-oil soap at the rate of 2 pounds to 50 gallons was used as a spreader and sticker for the arsenate of lead in plats III, IV, VII, VIII, and IX. The codling-moth trap was applied to all trees in plats I, III, V, and VII.

The sprays were applied by means of a power sprayer delivering about 225 pounds' pressure to two leads of hose. Two spray poles were employed in all treatments, one being operated from the tower and the other from the ground. In the calyx application Bordeaux nozzles were used, but these were replaced by whirlpool disk nozzles for the cover sprays.

As shown in Table 19, plats I to IV received, in addition to the calyx treatment, five cover sprays, three for the first brood and two for the later broods, and plats V to X were given one less cover spray, making a total of four, two of which were applied for the first-brood larvæ and two for protection against the second and third broods.

TABLE 18.—*Treatment of plats for the codling moth, Red Cross orchard, Grand Valley of Colorado, 1918.*

No. of plat.	Spray materials and supplemental control measures.	Spraying equipment.	
		Calyx spray.	Cover sprays.
I.....	Arsenate of lead, powder, 1 pound—50, and codling-moth traps.	Spray poles and Bordeaux nozzles.	Spray poles and whirlpool disk nozzles.
II.....	Arsenate of lead, powder, 1 pound—50.	do.	Do.
III.....	Arsenate of lead, 1 pound—50, fish-oil soap, 2 pounds—50, and codling-moth traps.	do.	Do.
IV.....	Arsenate of lead, 1 pound—50, and fish-oil soap, 2 pounds—50.	do.	Do.
V.....	Arsenate of lead, powder, 1 pound—50, and codling-moth traps.	do.	Do.
VI.....	Arsenate of lead, powder, 1 pound—50.	do.	Do.
VII.....	Arsenate of lead, 1 pound—50, fish-oil soap, 2 pounds—50, and codling-moth traps.	do.	Do.
VIII.....	Arsenate of lead, 1 pound—50, and fish-oil soap, 2 pounds—50.	do.	Do.
IX.....	Arsenate of lead, $\frac{1}{2}$ pound—50, and fish-oil soap, 2 pounds—50.	do.	Do.
X.....	Arsenate of lead, $\frac{1}{4}$ pound—50.	do.	Do.
XI.....	Check—unsprayed.		
XII.....	do.		

TABLE 19.—*Spraying schedule for the codling moth, Red Cross orchard, Grand Valley of Colorado, 1918.*

No. of plat.	Calyx spray.	Cover sprays—first brood.				Cover sprays—second and third broods.	
	A.	B.	C.	D.	E.	F.	G.
	Petals off, May 10-14.	3 to 4 weeks after A, June 3-5.	9 days after B, June 12-13.	12 days after B, June 15-17.	11 days after C, June 23-24.	8 to 9 weeks after A, July 8-11.	35 days after F, Aug 12-15.
I.....	First.	Second.	Third.		Fourth.	Fifth.	Sixth.
II.....	do.	do.	do.		do.	do.	Do.
III.....	do.	do.	do.		do.	do.	Do.
IV.....	do.	do.	do.		do.	do.	Do.
V.....	do.	do.		Third.		Fourth.	Fifth.
VI.....	do.	do.		do.		do.	Do.
VII.....	do.	do.		do.		do.	Do.
VIII.....	do.	do.		do.		do.	Do.
IX.....	do.	do.		do.		do.	Do.
X.....	do.	do.		do.		do.	Do.
XI.....	Check.						
XII.....	do.						

The results of these experiments are summarized in Table XX. The best results were obtained in plat IV in which 77.36 per cent of the fruit was free from worms and 60.36 per cent was free from both worms and stings. This plat was sprayed six times with arsenate of lead and fish-oil soap. Plat III, which had a like number of applications of the same materials and in addition was provided with the codling-moth trap, yielded 71.80 per cent of fruit free from worms and only 42.78 per cent free from both worms and stings. None of the other plats produced satisfactory commercial returns, and in plat VIII, which was sprayed five times with arsenate of lead and fish-oil soap, but 21.23 per cent of fruit was free from

worm infestation. Plat VI, which was given five applications of arsenate of lead alone, produced 37.88 per cent of fruit free from worms. It will thus be seen that in these experiments the addition of soap did not in all cases increase the percentage of worm-free apples, nor did the codling-moth trap appear to have any distinct value. In plats IX and X the arsenate of lead strength was reduced to one-half pound to 50 gallons, and, all factors being taken into consideration, the results indicate that this strength is as effective as 1 pound to 50 gallons. The unsprayed plats XI and XII produced 8.43 and 24.08 per cent of worm-free fruit, respectively.

The percentage of calyx entrants was somewhat higher in the unsprayed than in the sprayed fruit, but the difference in this respect is not so great as is usually found in spraying experiments for the control of the codling moth. The unsprayed fruit was comparatively free from the codling-moth sting, which is in accord with the experimental data obtained in the preceding years.

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TABLE 20.—Summary of spraying results for the codling moth, *Red Cross orchard, Grand Valley of Colorado, 1918.*

Plat.	Num- ber of trees ex- amined.	Total num- ber of apples ex- amined.	Total num- ber of worms (includ- ing extra).	Aver- age num- ber of worms for all apples.	Percentage of worms (including extra) en- tering apples.			Percentage of wormy apples infested.			Total num- ber of stings.	Aver- age num- ber of stings for all apples.	Per- centage of wormy apples free from stings.	Per- centage of worm- y apples free from stings.	Per- centage of all apples free from worms and stings.	Per- centage of all apples free from stings.	Per- centage of all apples free from worms and stings.
					At calyx.	At side.	At stem.	At calyx.	At side.	At stem.							
I.	8	8,466	5,402	1.49	6.67	92.98	0.35	9.94	89.54	0.52	12,378	2.90	36.73	59.15	57.22	49.56	33.85
II.	8	8,390	5,828	1.81	7.15	92.49	.36	11.76	87.99	.25	12,729	3.46	35.78	71.15	57.72	43.80	41.07
III.	8	7,413	2,855	1.37	14.15	85.08	.77	19.33	79.71	.96	8,683	2.66	46.69	59.57	71.80	55.94	42.78
IV.	8	9,478	3,096	.33	10.14	89.67	.19	14.64	85.13	.23	9,800	3.41	41.49	78.02	77.36	69.51	60.36
V.	8	9,820	10,301	1.05	7.27	92.34	.39	12.53	87.07	.40	10,175	2.66	48.54	80.68	39.11	61.10	31.56
VI.	8	4,318	5,196	1.20	6.68	93.19	.13	12.94	86.91	.15	9,837	2.28	32.48	61.12	37.88	43.33	23.16
VII.	8	5,847	5,268	1.60	9.84	89.88	.28	15.77	84.05	.18	8,888	1.52	46.50	63.69	43.80	54.03	27.89
VIII.	8	2,628	4,768	.90	8.18	91.48	.34	18.84	80.82	.34	3,927	3.74	51.26	92.47	21.23	60.00	19.63
IX.	8	3,145	3,080	1.73	10.00	89.61	.39	17.31	82.35	.34	4,702	2.11	37.27	69.47	43.43	51.22	30.17
X.	8	5,848	5,201	.97	9.55	89.68	.77	17.39	81.67	.94	4,702	2.88	57.38	94.84	46.55	74.83	44.17
XI.	8	2,489	4,549	1.83	16.73	82.26	1.01	33.39	65.86	.75	249	1.82	91.79	99.05	8.43	92.40	8.36
XII.	4	3,343	4,849	1.91	12.87	86.57	.56	24.59	75.02	.39	290	1.27	91.09	99.63	24.08	93.15	23.99

SUMMARY OF RESULTS.

The principal points of interest in connection with the experimental spray work in the Grand Valley of Colorado may be briefly summarized as follows:

SEASON OF 1915.

The highest percentage of fruit free from worms obtained in the experimental plats in 1915 was 72.22, in a plat which received six applications of arsenate of lead paste, 2 pounds to 50 gallons. In the unsprayed plat there was but 13.51 per cent of worm-free fruit. Arsenate of lime, both homemade and commercial, gave poorer control than arsenate of lead. In the control of larvæ that attempt to enter the fruit by way of the calyx cavity the results indicate that a low-pressure fine mist spray is as effective as a high-pressure coarse spray. The number of stings per apple was considerably less in the unsprayed than in the sprayed fruit.

SEASON OF 1916.

The best result during the season of 1916, 89.7 per cent of the fruit free from worm infestation, was obtained in a plat sprayed four times with arsenate of lead powder, 1 pound to 50 gallons. In the unsprayed plat 30.98 per cent of the fruit was uninfested. The primary object of the season's work was to test a coarse spray applied by means of a short rod equipped with a Bordeaux nozzle in comparison with a fine spray applied with spray poles and whirlpool-disk type nozzles. The results indicate that better control was secured with the finer sprays applied with the spray poles.

SEASON OF 1917.

The highest percentage of fruit free from worms in 1917 was 78.06, as a result of six applications of arsenate of lead, 1 pound of the powder to 50 gallons of water, to which fish-oil soap was added at the rate of 2 pounds to 50 gallons. Two unsprayed plats yielded 8.83 and 8.54 per cent of fruit free from worms. Another plat sprayed with six applications of arsenate of lead, but without fish-oil soap, produced 62.10 per cent of worm-free fruit, thus indicating that the addition of a soap spreader was of some value. The results with the codling-moth trap did not indicate that it materially aided in the control of the codling moth during the time of the experiments. Nicotine sulphate gave poor control and in combination with arsenate of lead apparently had very little value in reducing worm infestation or sting injury. Arsenate of lime gave unsatisfactory results. The dust treatments were even more ineffective. The plat in which the calyx spray was omitted was heavily infested at the calyx end. Five spray applications produced practically as much good fruit as seven.

SEASON OF 1918.

In 1918 in a plat sprayed six times with arsenate of lead and fish-oil soap at the usual strengths 77.36 per cent of the fruit was free from worms, this being the highest percentage of worm-free fruit obtained during the season. In two untreated plats, 8.43 and 24.08 per cent of fruit were free from worm infestation. The use of fish-oil soap in combination with arsenate of lead gave somewhat variable results. The codling-moth trap was of little value as a supplemental control measure. Arsenate of lead powder, one-half pound to 50 gallons, was about as effective as when used at twice this strength.

SUGGESTIONS FOR THE CONTROL OF THE CODLING MOTH IN THE GRAND VALLEY OF COLORADO.

The experience of the writers and others who are acquainted with Grand Valley conditions indicates that the codling moth presents a very difficult problem. As previously stated, there are two full broods of larvæ per annum and a partial third brood. The moth is extremely prolific because of the warm dry climate, and, as a result, the apples are exposed to large numbers of newly hatching larvæ practically every day during the development of the fruit.

The primary object of spraying is to cover the fruit and foliage with poison, and when this is properly distributed good protection is obtained for a time. It is, however, quite impossible in commercial spraying to coat completely all parts of the fruit, and further, as the apple develops in size it gradually outgrows the spray residue. The result is, that with numerous larvæ seeking a place of entrance, some will start feeding where there is no poison, gain entrance, and thus produce wormy apples. It is not commercially profitable to spray too many times during the season, but a sufficient number of applications should be made at such intervals as constantly to provide a protective coating of poison on the fruit, particularly when the larvæ are hatching in large numbers.

As a result of the life-history investigations in the Grand Valley and other places, it has been found that the development of the codling moth from the time of hatching of the first eggs of the season does not as a rule vary to any great extent and that an average can be struck which, over a series of years, would usually represent the approximate development of the insect with sufficient accuracy for spraying purposes.

Some growers of the Grand Valley have attempted to ascertain the time to spray by making observations in the orchard, such as inspection of the leaves for eggs and of the fruit for newly entered larvæ. The writers are inclined to believe that this particular method as practiced by the fruit grower is unreliable and frequently misleading, although regular and systematic inspections over a considerable

portion of the orchard will sometimes give information of value. As a rule, however, fruit growers have neither the time nor patience to undertake a careful orchard survey. On account of seasonal variations, calendar dates for making applications can not be depended upon, but a schedule based on certain intervals following the dropping of the blossom petals will usually result in timely spraying.

In formulating the control of the codling moth it is very important that the approximate time of the first hatching of each brood of larvæ and the relative number of worms that are developing from time to time be known. Complete and reliable data of this nature were obtained in the foregoing life-history studies, and with these data at hand it is believed that the most effective time for making the spray applications can be established.

The spray schedules that follow are based on the life-history studies of 1915 and 1916 and take into consideration the time when each brood begins to hatch, the time when the larvæ are hatching in large numbers, as well as the time when hatching occurs in maximum numbers. Three sets of schedules, I, II, and III, all starting from the time 90 per cent of the petals have dropped, are presented in Table 21, by reference to which it will be seen that schedule I calls for five applications and is intended for orchards having a relatively light infestation and for varieties on which the codling moth is not difficult to control; schedule II, six applications, for a medium infestation and for varieties on which the codling moth is moderately difficult to control; schedule III, seven applications, for a heavy infestation and for varieties on which the codling moth is most difficult to control.

The codling moth is normally abundant in the Grand Valley, and apples such as the Ben Davis, Schackelford, and other susceptible varieties will usually require schedule III, or seven treatments, especially if from previous neglect or other cause the infestation is very heavy; whereas, under similar conditions of infestation, varieties like the Winesap, on which the codling moth is more readily controlled, will require a smaller number of applications, as in schedules I or II. The degree of infestation varies somewhat from year to year and in the different fruit districts, and, as previously stated, the control of this insect varies with the different varieties. For these reasons, no one schedule will meet the demands of all the growers, and it will be necessary for each individual to forecast in advance what his conditions are likely to be and spray accordingly.

TABLE 21.—*Spraying schedules for the codling moth in the Grand Valley of Colorado.*

Application.	Spray application.	Time of application.	Applications.		
			I.	II.	III.
			Light infestation and with varieties on which the codling moth is not difficult to control.	Medium infestation and with varieties on which the codling moth is moderately difficult to control.	Heavy infestation and with varieties on which the codling moth is difficult to control.
Calyx spray.....	A.	Begin when 90 per cent petals have dropped and finish before calyces close.	First.....	First.....	First.
Cover spray, first brood.	B.	3 to 4 weeks after A, just previous to time when first-brood larvæ begin to hatch.	Second....	Second....	Second.
Do.....	C.	10 to 12 days after B, just previous to hatching of first-brood larvæ in large numbers.	.....	Third.....	Third.
Do.....	D.	15 to 17 days after B, just previous to hatching of first-brood larvæ in maximum numbers.	Third.....		
Do.....	E.	10 to 12 days after C, for late hatching first-brood larvæ.	.....	Fourth....	Fourth.
Cover spray, second brood.	F.	9 to 10 weeks after A, just previous to time when second-brood larvæ begin to hatch.	Fourth....	Fifth.....	Fifth.
Do.....	G.	24 to 26 days after F, just previous to hatching of second-brood larvæ in large numbers.	.....	.....	Sixth.
Cover spray, second and third broods.	H.	34 to 36 days after F, just previous to hatching of second-brood larvæ in maximum numbers and for protection against third-brood larvæ.	Fifth.....	Sixth.....	
Do.....	I.	15 to 17 days after G, for late hatching second-brood larvæ and for protection against third-brood larvæ.	.....	.....	Seventh.

From the foregoing schedules it will be seen that the first or calyx treatment is given in each schedule and that it should be started when about 90 per cent of the petals have dropped, and should be finished before the calyces close. The object of this application is merely to fill the calyx or blossom end of the fruit so that the worms that attempt to enter by way of the calyx will be killed by the poison lodged therein. Any spray applied after the calyx cups have closed will have no value in checking calyx worms. This application should be very thorough, and, for the sake of speed, it is advisable to use a spray under a pressure of about 225 pounds.

Schedule I consists of four cover sprays, the first of which should be applied three to four weeks after the calyx application, just previous to the time when the first-brood larvæ begin to hatch. This application will serve to coat the young fruit and foliage with poison as a protection against the early hatching worms. The second cover spray for the first brood should be applied 15 to 17 days later, just before the first-brood larvæ hatch in maximum numbers. The first cover spray for the second brood should be made 9 to 10 weeks after the calyx treatment, just prior to the time when the second-brood larvæ begin

to hatch. The next and last application should be made 34 to 36 days later, in advance of the hatching of the second-brood larvæ in maximum numbers and for protection against the third-brood larvæ.

Schedule II is similar to schedule I except that five cover sprays are used instead of four, the additional application being made for the first-brood larvæ. The second cover spray should be applied 10 to 12 days after the previous treatment so as to cover the fruit just in advance of the hatching of the first-brood larvæ in large numbers. The next application should be made 10 to 12 days later as a means of protection against the late hatching first-brood larvæ.

Schedule III includes a total of seven applications, the first four being similar to those of schedule II. But in schedule III, three applications should be made for the second and third broods, the first of which should be applied 9 to 10 weeks after the calyx treatment, previous to the hatching of the second-brood larvæ. The next application should follow in 24 to 26 days, just before the hatching of the second-brood larvæ in large numbers and the last should be applied 15 to 17 days later, for late hatching second-brood larvæ and protection against worms of the third brood.

AVOID PRESENCE OF SPRAY RESIDUE ON HARVESTED FRUIT.

Orchardists understand the importance of and will naturally give attention to the carrying out of any spraying schedule in such a manner as to obviate as completely as possible the presence of spray residue on fruit prepared for the market. Such residue is objectionable to consumers, and while there is little chance of injury resulting from its use, there is no necessity under average conditions to spray to an extent that results in much spray on the fruit at harvest time. A heavy coat of spray residue at harvest time is frequently due to an attempt on the part of the grower to protect his nearly ripened fruit from an abundance of late hatching worms. This condition would not be so common or serious if the proper action and same amount of endeavor were directed against the elimination of the first-brood worms.

During certain seasons of unusual worminess or with particularly susceptible varieties, seven treatments may not always give the desired results, but it is believed that in most instances seven thorough, well-timed applications will give as good results as can be economically obtained in the Grand Valley.

The foregoing schedules are based on the general average life history of the codling moth in the Grand Valley under normal climatic conditions. But if there should occur any unusual departure from the normal, a corresponding variation in the development of the insect is to be expected, and the schedule of applications should be modified accordingly. Small deviations, however, should not cause the fruit

grower to abandon his adopted schedule, since a matter of a few days one way or the other is not likely to affect the ultimate results to any marked extent.

Above all, the fruit grower should pay particular attention to spraying for the first-brood larvæ and make every effort to poison as many of these as possible. If all of the first-brood worms were killed there would be none of the second or third broods with which to contend. Upon inspection of their orchards early in the season, fruit growers sometimes conclude that there are so few worms present that it is unnecessary to make additional spray applications for the first brood. Unfortunately, it is not always realized that the presence of a comparatively few larvæ early in the season will often result in large second and third broods, which frequently will cause an enormous loss despite the most thorough subsequent spraying. The fruit grower should therefore bear in mind that during the early part of the season, while the fruit is small and the skin is not very waxy, it is easier to coat it thoroughly with poison and thus kill the worms than later in the year when the apples have grown larger and the skin has become smoother. Unless the fruit grower makes every effort to reduce to the minimum the number of first-brood larvæ, he will have small chance of success against the later broods. Neglect to spray with thoroughness and timeliness against the first brood of worms can never be economically or successfully overcome by sprays applied late in the season.

SPRAY MATERIALS.

Arsenate of lead at the rate of 1 pound of the powder or 2 pounds of the paste to 50 gallons of water is recommended as the most satisfactory poison for use against the codling moth. For convenience in handling and storing, the powdered product is preferable to the paste.

Although the experimental data did not always indicate that the addition of fish-oil soap to the arsenate of lead spray was of value, it is believed, nevertheless, that the use of soap, 2 pounds to 50 gallons, will generally increase the efficiency of the spray on account of the spreading qualities of the soap. Soap, however, should never be used with strongly alkaline water.

SPRAYING EQUIPMENT.

To spray the orchard as quickly as possible during the critical periods, it is recommended that a power sprayer of ample capacity and capable of supplying three leads of hose with a pressure of 225 to 250 pounds be used. In spraying large trees a spray tower, erected on top of the outfit, will enable the operator to cover the upper parts of the trees more thoroughly. A tank filler is almost a necessity and each sprayer should be provided with this device. It is also important

to have well-made hose of sufficient length and hose couplings and clamps that will stand the strain of the work without breaking or allowing the hose to be forced off during the spraying operations.

As previously stated, it is believed that the use of spray poles equipped with the whirlpool-disk type of nozzles will result in a larger percentage of clean fruit than if the short rod and Bordeaux nozzle or the spray gun are used. The last two methods of spraying, however, will save considerable time and it is therefore a question of the value of time against a somewhat greater quantity of fruit free from worms. The choice of method will depend upon availability and cost of labor, weather conditions, size of orchard, and number of spray machines, severity of infestation, variety of fruit, and other factors. Under some circumstances the grower may find it an advantage to use the spray gun for the calyx application and the first cover spray, changing to the poles and finer sprays for the later treatments when the fruit is larger and the skin is smoother, more waxy, and more difficult to coat with the spray liquid.

SUPPLEMENTAL CONTROL MEASURES.

BANDING.

Despite the most thorough spraying some first brood larvæ will escape the poison, and after completing their feeding period within the fruit will leave it and spin their cocoons on the tree trunk and later develop into moths which will in turn produce second-brood larvæ. As a means of catching these larvæ the banding method may be practiced. This consists of scraping the trunk to remove the loose bark, thus destroying most of the places where the larvæ hide, and then placing around the trunk a burlap band, folded into two or three thicknesses to a width of about 6 inches. These bands should be examined every 10 days from about the middle of June to August 31, and all of the larvæ and pupæ found beneath should be killed. A final examination should be made any time after the fruit is harvested. The banding method, if properly worked from year to year in conjunction with thorough spraying, will gradually reduce the number of individuals in the orchard so that a larger percentage of worm-free fruit will be obtained than with spraying alone.

CODLING-MOTH TRAP.

A codling-moth trap has been devised as a substitute for the banding method. This device will serve the same purpose as banding and will obviate the necessity of working the bands during the growing season when labor is usually much needed for other duties. While the spraying experiments do not indicate any pronounced benefit through the use of the codling-moth trap, it should be borne in mind that this device was used only one season and then only in a part of

each of the orchards; hence there was no chance to determine what cumulative effect it might have if used over a series of years and if applied to all of the trees in the orchard. Since we have no experimental data to indicate the cumulative value of the trap the writers are not in a position to make any recommendations, but for those who wish to give the trap a trial the following method of manufacture is suggested.

MANUFACTURE.

The materials needed for the manufacture of the codling-moth trap are as follows: Medium to heavy burlap, ordinary black-painted or japanned wire screen having 12 meshes to the inch, a folding machine such as that used by tanners to fold the edge of tin sheeting, and a crimping machine such as that used to reduce the end of stove pipe.

The burlap is cut into strips 6 inches wide and folded into three thicknesses by any convenient method. Wetting the burlap will make it fold more easily and remain better creased. To assist in this, however, it is well to roll the burlap up in flat rolls of any convenient size so that they can be easily handled in the field.

The wire screen is also cut into strips 6 inches wide and of any convenient length, depending on the length of the machine used to fold the edges. The edge of each strip should be folded at least once, preferably twice, using the folding machine mentioned above or any other convenient method. This fold should not be over three-eighths to one-half of an inch wide if folded once and not over one-fourth of an inch wide if folded twice. It is essential that the wire should be folded at least once and preferably twice, as the edges can then be crimped much better in the crimping machine and a more desirable bulge produced. Both edges of the strip are then run through the crimping machine, which should be set to make a fairly deep crimp without cutting the wire and about three-fourths to one inch from each edge. This crimp will aid greatly in giving, as stated above, a desirable bulge to the wire when it is applied to the tree, and further it will allow for the expansion of the tree trunk as it grows throughout the season. As the wire comes from the crimping machine it can well be rolled up into small rolls, which will greatly assist in keeping the crimp intact and also facilitate the manipulation of the wire in the field. If the crimping machine mentioned above can not be had, some other method, such as tucking the edges, must be adopted to give the desired bulge and to keep it away from the burlap on the tree.

APPLICATION.

The materials needed for the application of the codling-moth trap to the tree are as follows: A supply each of burlap and wire screen prepared as described above, a supply of slate nails about an inch or

more long, 10-ounce bill-posting tacks, tinner shears, a claw hammer, tar such as that used for roofing purposes (sometimes called "pitch tar"), a melting pot or a small pail conveniently arranged over a flame, and a small dauber.

The strip of folded burlap is then placed completely about the trunk of the tree to be trapped. It may be placed at any convenient height between the lowest limb and the ground, and an overlapping of an inch or two should be left to allow for the expansion of the tree. The loose bark should be scraped from the trunk, lower branches, and the crotches of each tree on which the codling-moth trap is applied in order to destroy as many places as possible where the codling-moth larva might spin its cocoon and there transform to the adult or moth stage. The burlap should be held in place by slate nails about an inch in length driven in at several points around the tree trunk so that the head projects not less than half an inch beyond the burlap, preferably three-fourths of an inch. This is essential in order to hold the wire safely away from the burlap at such a distance as will prevent the pupæ, just before the moths emerge, from wriggling up to or through the meshes of the wire and the moths from emerging on the outside of the trap.

With the burlap in place and the slate nails in their proper position, the wire screen, as prepared above, is ready to be tacked into place. Start at any convenient point and in any convenient direction around the tree by putting one tack in the corner on the lower edge of one end of the wire-screen strip, holding the strip so that the burlap band will be in the middle. Then place a tack in the corner on the upper edge, shoving down on this edge slightly, so as to spring the wire away about $1\frac{1}{2}$ inches or more from the tree at this point. Proceed around the tree trunk with the wire, holding it so that the burlap will be in the center all the way around and placing just enough of the 10-ounce bill-posting tacks along the edges of the wire to hold it snugly to the tree at all points, particularly where there are slight depressions or hollows which can not be sealed over with the tar, as outlined below.

Here care should be taken not to stretch the wire while it is being tacked to the tree, as this will pull out the crimp and make the formation of a desirable bulge rather difficult. Care should also be taken while the wire is being tacked into place to push the two edges together somewhat in order to increase the bulge already made by the crimping. This bulge should be large enough so that the middle of the strip will be approximately 1 inch from the burlap at every point. It is entirely possible to produce a bulge of over 2 inches, provided the wire is properly crimped and the edges are pushed together in the proper fashion. A little practice, however, will develop considerable skill along this line. An overlapping of

several inches should be left when the wire has been completely fastened around the trunk of the tree, and this overlapping should be stretched slightly over the wire beneath, so as to make a tight joint. If, as pointed out above, care is taken to produce a bulge sufficient to hold the wire well away from the burlap, to fit the wire snugly to the tree and make the overlapping tight, the codling-moth trap will remain in perfect operation throughout the season. It will then be practically impossible for the pupæ, just before the moths emerge, to work their way up to the wire, allowing the moths to emerge on the outside of the trap, a thing which is sure to happen when the wire is close to the burlap.

Care should be taken that there are no openings between the wire and the tree trunk through which moths may escape from the trap. These can be prevented by placing a thin coating of ordinary roof tar over the edges of the trap. This is a very practical and convenient method of making traps moth-tight. The tar can be conveniently melted in a small melting pot or pail held over a flame and can be applied best by means of a small stick with a bit of cloth on the end. Tar can not be applied easily with a brush. In applying the tar, roll the stick or the dauber toward the tree as it is passed along the edges of the trap. The tar need not be applied until shortly before the time the first moth of the first brood emerges.

MAINTENANCE.

When once attached to the tree as outlined above and carefully sealed with tar, the codling-moth trap should remain in perfect operation throughout the season and should require very little attention. In some cases an inspection the following spring to close up any holes which may have formed will be sufficient to put the trap in condition for another year.

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Contribution from the Bureau of Plant Industry

WM. A. TAYLOR, Chief

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August 15, 1921

THE RELATION OF WATER-RAKING TO THE KEEPING QUALITY OF CRANBERRIES.

By NEIL E. STEVENS, *Pathologist*, and H. F. BERGMAN, formerly *Scientific Assistant*,
Fruit-Disease Investigations.

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METHODS OF HARVESTING CRANBERRIES.

THE GREATER PART of the cranberry crop of the United States is harvested dry, being either picked by hand or gathered by scoops or rakes of various designs. Most growers, indeed, take great care not to allow the berries to be picked when wet with dew. The practice of water-raking—that is, of flooding the bog and raking off the berries as they float on or near the surface of the water—has, however, developed to some extent in Wisconsin and has given rise to so much discussion as to its effect on the keeping quality of the fruit that the question has been made the subject of a special investigation by the writers.

The present bulletin, which deals with the water-raking problem only in its relation to the keeping quality of the fruit, is based on investigational work in Wisconsin extending over three seasons. In 1918 a general study was made of harvesting methods and conditions throughout the cranberry regions of the State, and Wisconsin berries were followed through the storage season in the markets of Minneapolis and Chicago. In 1919 attention was confined chiefly to a

study of the flooding waters in various parts of the State. In 1920 careful comparative shipping and storage tests were made of berries harvested in various ways.

The investigation of water-raking has been confined to the State of Wisconsin, because this method of harvesting cranberries is practiced nowhere else. Indeed, it is doubtful whether it would be practicable elsewhere, even if desirable. To bring about its introduction on the large bogs of Massachusetts and New Jersey such extensive alterations would be necessary as to make it out of the question unless the practice could be proved to be extraordinarily beneficial.

STORAGE CONDITIONS.

Aside from the action of insects or actual crushing, cranberries in storage spoil chiefly from decay caused by fungi or from smothering. These causes of spoilage and some of the factors which influence them have been discussed in several papers (4, 5, 6, and 9).¹ It is obvious that those conditions which have been proved injurious to the keeping quality of dry-raked cranberries will also be injurious, perhaps even more seriously so, to water-raked berries. Careful handling, low temperatures, and good ventilation will improve the keeping quality of water-raked cranberries as of cranberries harvested in other ways.

A striking example of the importance of good ventilation in the storage of water-raked cranberries was observed at Minneapolis in 1918. Here water-raked cranberries of the same variety (Searls), from the same marsh, and handled in the same way were stored in picking boxes and in barrels. On December 9, 1918, the average condition of typical samples showed 22 per cent of spoiled berries in the lot stored in boxes and 34 per cent in those in barrels.

It is obvious and must be constantly borne in mind in considering the material presented in this bulletin that the results here reported can not be expected to apply to all cranberry conditions. Too many variable factors are involved to make it possible to duplicate exactly conditions or results. The variation in the kinds and quantity of fungi present on different bogs and even in different seasons on the same bog has been frequently remarked. Different varieties of cranberries are known to have quite different keeping qualities and may well be differently affected by water-raking. Different water and climatic conditions would undoubtedly have an important effect on the results. To mention only two examples: One could not expect water-raked berries to dry so quickly in the generally humid atmosphere of the cranberry regions of Washington and Oregon as in the much drier air of Wisconsin, and the relatively warm flooding water

¹ The serial numbers in parentheses refer to "Literature cited" at the end of this bulletin.

of New Jersey would have a different effect on the berries than the much cooler water of Wisconsin. The results of the experiments here described will be useful even to Wisconsin growers only when considered in connection with the conditions on their own marshes and with their previous experience.

PRESENT PRACTICE IN WATER-RAKING.

The usual practice in water-raking is to flood the vines so that the cranberries float on or near the surface. They are then harvested with rakes much like those used in dry-raking, but usually somewhat larger and with the teeth longer and farther apart. After the berries are harvested they are dried as soon as practicable, usually by pouring them into specially made drying crates, which are then piled and an empty crate placed on top of the pile to protect the berries from the sun. A common type of crate is 24 by 24 inches in size by 6 inches deep, with the bottom and two sides made of laths spaced to permit the free circulation of air. The crates are usually filled one-fourth to one-third full, and an open space is left in the middle to increase the ventilation. When the berries are dry they are removed to the storehouse. A few growers with large and well-ventilated storehouses follow the practice of taking the berries directly into the storehouse after they are raked from the water and placing them in shallow crates, which are so piled as to permit the free circulation of air.

If there is injury to berries from water-raking it probably arises either from their submergence or in the process of drying. Several important factors in each of these processes will be briefly considered.

IMPORTANT FACTORS IN DRYING CRANBERRIES.

The universal experience of cranberry growers agrees with the results of experiments conducted in Massachusetts and in Maine in indicating that it is injurious for cranberries to remain damp for a long time in storage (6, p. 122, and 9, p. 9). It is therefore to be expected that, other things being equal, the more quickly berries are dried after being water-raked the better. The time required for drying will depend, first of all, upon the weather and, second, upon the way they are handled. The most favorable conditions for drying are obviously a good breeze and a low humidity, conditions which apparently are somewhat more frequent in Wisconsin (3) than in other cranberry regions.

The weather conditions are, of course, beyond the growers' control. The rate of drying, however, is directly influenced by the manner in which the cranberries are handled. Berries will dry much more quickly if the drying crates are not filled too full, the grass and

leaves carefully removed, and the crates piled in a favorable location. It goes without saying that the more quickly the berries are placed in the drying crates after they are harvested the better. It is important, too, that they be handled as carefully as possible to avoid bruising, for even slight injuries have been shown to increase decay (9, p. 13). In this respect there is some advantage in placing the berries directly in the crates in which they are to be stored.

INJURY DURING SUBMERGENCE.

That cranberries are injured and may be wholly spoiled by long-continued submergence is well known (9, p. 5, and 6, p. 117). The extent of the injury which will occur in a given time is governed by various factors, among which are the age of the berries, the temperature of the water, and the oxygen content of the water. It is highly probable that the variety of the berry and the fungi present may influence the amount of injury, though no definite statements on this point are possible at present.

AGE OF THE BERRY AT THE TIME OF SUBMERGENCE.

In general, any factor which influences the oxygen requirement of the cranberry affects the extent of the injury due to smothering. Green berries respire more rapidly than ripe ones, and green berries are therefore the first to suffer from smothering when flooded. (See also 6, p. 118.) This is well shown by the relative percentage of spoilage in green (not fully colored) and ripe (fully colored) water-raked berries examined at Chicago and Minneapolis in 1918, as shown in Table I.

TABLE I.—*Keeping quality of green and ripe water-raked cranberries grown on the same bog in Wisconsin in 1918.*

Variety.	Where examined.	Date examined.	Spoiled berries (per cent).	
			Green.	Ripe.
Metallic Bell.....	Chicago, Ill.....	Oct. 27.....	7	7
Do.....	do.....	Dec. 7.....	48	32
Searls.....	Minneapolis, Minn.....	Dec. 9.....	54	34

In the case of the Metallic Bell variety the first counts were made when the barrels arrived at Chicago, and the second were from the same barrels about six weeks later. The two lots of the Searls variety examined were stored in barrels under the same conditions. The green berries were under water at the time of flooding not more than two and a half days, while the late-picked berries were in the water for three to five days. Notwithstanding this fact, the late-

picked berries show better keeping quality than those picked early. The greater injury to the light-colored early-picked berries is apparently due to the higher respiration rate of these berries.

TEMPERATURE OF THE WATER.

The effect of temperature is very important in determining the rate of respiration. Morse (8) has recently proved that in the cranberry, as in many other fruits (7), the rate of respiration is twice as rapid at 10° as at 1° C. and that the rate doubles again at 20° C. This means that the amount of oxygen necessary to maintain the normal activity of the berries is twice as great at 10° and four times as great at 20° as at 1° C. On the other hand, the capacity of water for holding oxygen diminishes with the rise of temperature. Other things being equal, then, the colder the water the better it is for use in water-raking. It is obvious that in this respect the conditions are more favorable for continued flooding in Wisconsin than in Massachusetts or New Jersey.

OXYGEN CONTENT OF THE WATER.

The importance of the flooding water in the cranberry industry has led to a careful study of different water supplies and their relation to injury from flooding by one of the writers (Bergman). These studies, which are in part unpublished, indicate that a very important factor, perhaps the most important factor in water injury, is the oxygen content of the water. Water having a high oxygen content will cause much less injury in a given time than that having a low oxygen content. The oxygen content of flooding water under natural conditions is determined by atmospheric pressure, temperature, the quantity of organic matter in the water and substratum, and the light intensity.

As atmospheric pressure varies only slightly from day to day, this factor may for practical purposes be disregarded. The temperature influences both the capacity of the water to hold oxygen and the rate at which the oxygen is taken up from the water by organic matter. Water reaches its greatest capacity for oxygen at 0° C. This capacity decreases with the rise of temperature. On the other hand, the rate of oxidation of organic matter increases with the rise of temperature. From both points of view, then, the cooler the water the more favorable for a high oxygen content.

The presence of decaying organic matter in the water or in the substratum reduces the oxygen content of the water. Decay is a process of oxidation, and decaying organic matter in the water or the substratum can obtain oxygen only from the water. Therefore, it decreases the oxygen content of the water in proportion to the amount of organic matter present and the rate of oxidation, which, in turn, depends on the temperature.

In this connection the source from which the water is drawn or the character of the soil in the reservoir is important. The water of a lake with a muck bottom and swampy margin has generally a lower oxygen content than one with a sand or gravel bottom. The studies of Birge and Juday (2) show that this applies to Wisconsin lakes and the studies of one of the writers (Bergman) have shown that the oxygen content of water from cedar-swamp reservoirs in Massachusetts was only 10 to 40 per cent of that in clear pond water at the same time. For the same reason, the water of reservoirs constructed on marshes is usually low in oxygen content.

The influence of light intensity on the oxygen content of flooding water and its relation to the water injury of submerged cranberry plants has been considered in another paper (1). Briefly, it may be stated that whereas the process of respiration, in which oxygen is taken up from the water by the submerged plant, goes on both in light and in darkness, the process of photosynthesis, in which oxygen is given off to the water by the plant, can take place only in the light. On a clear day the oxygen content of the water on a flooded cranberry marsh in growing condition increases. On the other hand, at night or in cloudy weather the oxygen content of the water is reduced, and if the cloudiness persists for two or three days the oxygen content may become very low and injury may result.

OXYGEN CONTENT OF WATERS USED IN FLOODING CRANBERRY MARSHES IN WISCONSIN.

During September of the years 1918 and 1919 determinations of the oxygen content of more than 130 samples of water from various marshes in Wisconsin were made. Winkler's titrimetric method for determining the oxygen content of water (10, p. 2843) was used in all cases.

From these analyses, of which Table II gives a few typical examples, it is evident that the oxygen content of the flooding water of Wisconsin cranberry marshes is generally below saturation. In some cases the deficiency is very marked. This is due to the fact that in practically all cases the water is held in reservoirs constructed on marshes.

These analyses show that the oxygen content of water in reservoirs and on the flooding sections of marshes increases during the day and that the increase is greater on clear days than on cloudy ones. This is illustrated by the analyses of reservoir water at Black River Falls on September 10 and 11, 1919. On September 10, a cloudy day, the oxygen content of the water at the north end of the reservoir increased from 3.22 c. c. per liter at 11.30 a. m. to 3.74 c. c. per liter at 4.45 p. m. On September 11, a clear day, the oxygen content of the

water at the same station increased from 2.85 c. c. at 10.15 a. m. to 4.28 c. c. per liter at 4.30 p. m.

TABLE II.—Oxygen content of the water at various hours of the day in the reservoirs of cranberry marshes in Wisconsin.

Locality.	Date.	Hour.	Temperature (° C.).	Weather.	Oxygen perliter (c. c.).	Approximate saturation (per cent).
1918.						
Cranmoor.....	Sept. 25	9 a. m.....	13	Clear.....	5.58	77
Do.....	do.....	10 a. m.....	13	do.....	5.77	80
Walker.....	Sept. 26	11.30 a. m.....	15	do.....	6.92	98
Black River Falls.....	Sept. 27	10 a. m.....	15	Cloudy.....	4.41	64
Beaver Brook.....	Sept. 29	11 a. m.....	10	Clear.....	5.11	74
1919.						
Do.....	Sept. 6	11 a. m.....	15	do.....	5.19	75
Black River Falls.....	Sept. 10	11.30 a. m.....	15	Cloudy.....	2.93	42
Phillips.....	Sept. 16	2 p. m.....	15	Clear.....	3.74	54
Cranmoor.....	Sept. 19	2 p. m.....	15	Cloudy.....	4.52	65
Walker.....	Sept. 20	11.45 a. m.....	17	Clear.....	2.22	33
Beaver Brook.....	Sept. 6	11 a. m.....	15	do.....	5.19	75
Do.....	Sept. 8	4.25 p. m.....	14	Cloudy.....	5.9	86
Do.....	Sept. 8	7.45 a. m.....	15	Clear.....	5.03	72
Do.....	Sept. 8	3.40 p. m.....	15	Cloudy.....	6.00	86
Black River Falls.....	Sept. 10	11.30 a. m.....	15	do.....	3.22	46
Do.....	Sept. 10	4.45 p. m.....	15	do.....	3.74	53
Do.....	Sept. 11	10.15 a. m.....	15	Clear.....	2.85	41
Do.....	Sept. 11	4.30 p. m.....	17	do.....	4.28	64

The difference in the oxygen content of the water on a clear day as compared with a cloudy one is not as great in this case as in many instances observed in Massachusetts. This is due, no doubt, to the lower temperatures and poorer illumination in the case of the Wisconsin waters, as these were examined in September, while those in Massachusetts were examined in summer.

The increase in the oxygen content of flooding water during the day, as explained in other papers by one of the writers (Bergman), is due to the photosynthetic activity of algæ and other aquatic plants in the reservoir. This activity must necessarily be less in the cool and relatively darker days of September than in midsummer.

EXPERIMENTAL TESTS OF THE KEEPING QUALITY OF WATER-RAKED CRANBERRIES.

The observations of the writers in the markets during 1918 indicated that water-raked berries often show poorer keeping quality than dry-raked or dry-picked berries from the same marsh. Table III gives typical examples of the differences frequently observed.

Figures such as those given in Table III, while suggestive, are open to criticism, since the lots were not in all cases strictly comparable, having come from different places in the bog, and the water-raked berries were not harvested under the best possible conditions. Some of the Searls variety, on which the report is made, for example, were under water from three to five days.

TABLE III.—*Keeping quality of cranberries of the same variety harvested by the wet and dry methods from the same marsh, commercially handled, in 1918.*

Variety.	Where examined.	Date examined.	Spoiled berries (per cent).		
			Water-raked.	Dry-raked.	Dry-picked.
Metallic Bell.....	Chicago, Ill.....	Nov. 27.....	20	8	.....
Do.....	do.....	Dec. 3.....	14	8	.....
Do.....	do.....	Dec. 7.....	32	11	.....
Searls.....	Minneapolis, Minn.....	Dec. 9, 10, and 11.....	22	.....	10

To furnish a basis for a comparison more accurate than that shown in Table III, a special effort was made in 1920 to obtain a fair comparison of dry-raked and dry-picked cranberries with water-raked berries handled in different ways. The berries used in the various comparative tests were of the same variety and were gathered from the same sections of the marsh. The harvesting, drying, storing, and packing were all done under the close observation of one of the writers, and careful note was taken of the length of time the berries were submerged and the time occupied by the various lots in drying.

Because of the importance of weather conditions in drying water-raked cranberries, the weather data for the period during which the harvesting tests were carried on are presented in Table IV. These data were taken with standard instruments of the United States Weather Bureau by the local observer, Mr. C. L. Lewis, jr.

TABLE IV.—*Weather data at Beaver Brook, Wis., from September 14 to October 2, 1920.*

Date.	Temperature (° F.).		Precipitation (inches).	Frost.	Date.	Temperature (° F.).		Precipitation (inches).	Frost.
	Maximum.	Minimum.				Maximum.	Minimum.		
September 14	84	60	.....		September 23	75	63	0.10	
September 15	77	45	.....		September 24	74	50	.....	
September 16	74	48	.....		September 25	86	56	.01	
September 17	86	47	.....		September 26	72	38	.....	
September 18	76	41	1.13		September 27	70	40	.....	
September 19	54	42	.03		September 28	53	32	.....	
September 20	70	51	.23		September 29	48	28	.02	Light.
September 21	79	54	.....		September 30	52	23	.....	Do.
September 22	81	63	.....		October 1.....	60	28	.....	Do.

Up to September 18 the weather was particularly favorable for drying water-raked berries. Not only was it warm and dry, but there was a strong wind. Wet berries placed in the drying crates at 10 a. m. were dry to the touch at 5 p. m. It is, then, not surprising that under these conditions the best results were obtained.

Most of the experiments were made with berries from the marsh at Beaver Brook, Wis. This locality is especially favorable for the work,

since the marsh has considerable acreages of a single variety, water-raking is regularly practiced, and both barrels and half-barrel boxes were available for the shipping tests. In all, 21 experimental lots, including 76 boxes and barrels, were prepared, shipped to three different markets, and examined at intervals from October 30, 1920, to February 3, 1921. The results of these experiments are summarized in Tables V and VI.

TABLE V.—Average keeping quality of cranberries (*Searls variety*) harvested in various ways.

Date examined.	Spoiled berries (per cent).			
	Hand-picked.	Dry-raked.	Water-raked.	
			Dried Sept. 14-17.	Dried Sept. 25 to Oct. 1.
November 4-6, 1920.....	5.0	2	4.8	10.6
November 22-24, 1920.....	8.3	3	8.4	17.0
December 14, 1920.....	15.2	.....	16.0	.....
January 4, 1921.....	.....	8	16.5	.....

The figures given in Table V² are in all cases the averages of several lots and include among the water-raked cranberries only those which were dried as promptly as possible under the prevailing weather conditions. The results indicate clearly the importance of prompt drying. The water-raked berries dried during the very favorable weather of September 14 to 17 showed practically the same keeping quality as the hand-picked berries, though not so good as the dry-raked fruit, while those harvested during the less favorable weather were distinctly inferior.

The effect of rapid drying is shown in still another way. Ten tests were made in which several boxes of water-raked berries were separated into two lots, one lot being carefully placed in the drying crates so as to permit rapid drying, while the other lot was put in the drying crates rather carelessly, the crates being filled about half full and the berries not separated in the middle of the crate. When the various lots were examined early in November the carelessly dried berries showed 14 per cent more rotten berries than those well dried. This difference (9.6 per cent of the total carelessly dried berries as compared with 8.4 per cent of the carefully dried berries) amounted

² The superior keeping quality of the dry-raked cranberries, as compared with the hand-picked berries, is probably due, at least in part, to the slight bruising which berries often suffer in hand-picking. The importance of these slight bruises has been shown in other experiments (9, p. 13), and large berries seem to be more easily injured by hand-picking than smaller ones, as was shown by comparative tests of hand-picking and dry-raking made in New Jersey in 1916, on the Early Black, Howe, and Centennial varieties. In almost all tests dry-raked cranberries have kept somewhat better than those hand-picked (9, p. 14, and 5, p. 198). On the other hand, in dry-raking, a considerable number of berries are lost.

to 1.2 per cent of the volume of either lot of the berries in the test. If the difference seems small, it should be remembered that the lots were identical and their treatment the same, except that they were placed in the drying crates somewhat differently. Moreover, during the early part of the test, the weather conditions were so favorable for drying that even the carelessly handled lots dried very quickly.

The injury resulting from permitting cranberries to remain wet after picking is more clearly shown by two tests in which the berries were kept wet for several days. In the first test one lot of berries was dried as soon as possible after harvesting; a second lot from the same section harvested on the same day (September 17, 1920) was kept wet over night, then dried in good condition; a third lot from this section was kept wet for three days. The third lot showed more than three times as many rotten berries as the first. A similar test was carried out the following week. Three lots of berries harvested on September 25 from the same section were handled as follows: One lot was dried as soon as possible, the second lot was permitted to remain wet in the picking crates over night, and the third lot was left in the picking crates for two days. In this test, as in the previous one, the lot which remained wet for the longest time showed markedly inferior keeping quality. The results of these tests are given in Table VI.

TABLE VI.—Average keeping quality of cranberries from the same section, treated in different ways after water-raking.

Treatment.	Spoiled berries (per cent).	
	Nov. 5-6, 1920.	Dec. 14, 1920.
Lot 1, September 17:		
Dried as soon as possible.....	4.5	16.0
Kept wet over night.....	11.9	21.7
Kept wet three days.....	15.8	
Lot 2, September 25:		
Dried as soon as possible.....	10.0	
Kept wet over night.....	11.0	
Kept wet two days.....	15.0	

Long-distance shipments, to Washington, D. C., and to San Jose, Calif., of commercially handled water-raked and hand-picked berries from Beaver Brook, Wis., gave somewhat conflicting results, but in general confirmed the results of the more careful tests that under the conditions in 1920 there was very little difference in keeping quality between hand-picked berries and those which had been water-raked and dried under favorable conditions.

One comparative test of hand-picked and water-raked berries was made in which the water-raked berries were dried in the storehouse. In this case the water-raked berries showed inferior keeping quality,

having about one-third more rotten berries than those which were hand-picked. A single test does not furnish a sufficient basis for safe conclusions, but it seems probable that this method will have to be confined to the growers who have unusually large and well-ventilated storehouses and who are able to dispose of their crops fairly early in the season.

During the season of 1920 an attempt was made to determine the length of time during which cranberries may safely be submerged before picking. Unfortunately, these tests were delayed until the very last of September, when the water was cold, and the results were inconclusive.

SUMMARY.

Investigations carried on through three seasons in Wisconsin indicate that ventilation is of great importance in the storage of water-raked cranberries, as of cranberries harvested in other ways.

Green berries are more easily injured in water-raking than ripe (fully colored) berries.

Cool water and water having a high oxygen content are much less likely to cause injury in water-raking than warm water or that having a low oxygen content.

Water used in flooding Wisconsin cranberry marshes varies considerably in oxygen content.

The oxygen content of water in reservoirs and on the flooding sections of marshes increases during clear days and decreases at night.

Under the most favorable conditions the writers have been able to obtain, the keeping quality of water-raked cranberries was somewhat inferior to that of dry-raked berries from the same sections and about equal to hand-picked berries.

Berries which are permitted to remain wet for some time after water-raking show decidedly poorer keeping quality than those quickly dried and are, of course, inferior to those which are hand-picked or dry-raked.

PRACTICAL SUGGESTIONS.

Whether berries shall be water-raked, dry-raked, or hand-picked must be decided by each grower and for each marsh separately, after taking into consideration the cost of the various methods, the available labor, the kind and quantity of water available, and especially his experience with the marsh as regards the keeping quality of the fruit produced.

If water-raking is undertaken, the berries should be under water as short a time as possible, should be well colored when harvested, and should be dried as promptly as possible.

Small flooding sections are a distinct advantage in water-raking, as the berries under such conditions need be submerged for only a short time.

The cooler the flooding water, the better the chance of successful water-raking. Clear spring or brook water is preferable to dark-colored swamp water.

Intelligent and conscientious assistants to care for the drying of the berries are absolutely necessary if water-raking is to be successfully practiced.

In packing water-raked cranberries any lots which have dried slowly because of unfavorable weather or other conditions should be kept separate and marked or sold separately.

Because of the variation in keeping quality of water-raked cranberries due to the conditions under which they are handled, it is doubtful whether water-raked berries should ever be mixed with or included with dry-raked or hand-picked berries.

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UNITED STATES DEPARTMENT OF AGRICULTURE



BULLETIN No. 961

Contribution from
the Office of Farm Management and Farm Economics
H. C. TAYLOR, Chief



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STANDARDS OF LABOR ON THE HILL FARMS OF LOUISIANA.

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INTRODUCTION.

This bulletin is a statement of the prevailing standards of labor for crews of various sizes at field and crop work and the labor requirements of crops per acre for the hill sections of Louisiana. Though the data presented are strictly applicable only to that locality, it is believed that they will apply in large measure to the upland portions of the other Cotton Belt States where types of farming, implements used, kind of labor employed, and character of soil are similar. In making this statement the intention is not to convey the idea that conditions in all of these localities are uniform, but that such differences as there are in soil, topography, kind of labor used, weeds, etc., are not sufficient to affect materially the amount of work done per day or the labor requirements per acre. The climate throughout these States varies so little that the season and time available for a given operation are about the same throughout the region, except that the season is a little earlier or a little later as one goes south or north of the area surveyed.

It is believed that the information in the following pages will be of great help in replanning a farm or in readjusting crop acreages so as to utilize better both man and animal labor, or in determining the kind and sizes of new machinery to purchase. It should also be an

aid in planning the year's work, especially in determining how large an acreage can be handled by a given crew at the busiest season of the year, or how much extra help will be needed at a given time. It is understood, of course, that no plans or work schedules which may be worked out from this information can be followed blindly without reference to variations in weather and other conditions.

SCOPE AND METHOD OF STUDY.

The data for this bulletin were obtained by personally interviewing several hundred farmers in the hill section of Louisiana. From these men there were obtained 677 detailed reports on the principal crops grown. These reports cover all the operations performed on each crop, the size of crew, the implements used, and the farmer's estimate of the acreage.

The area in which the data were collected is the northwest quarter of the State of Louisiana. The climate is warm and even, the growing season extending from about March 1 to November 5, or usually about 250 days. The rainfall averages about 45 inches, and is well distributed throughout the growing season. The fall months are usually the driest of the year. This part of the State is rolling and has many streams. More than half of the area is in woodland. The farms on which the records were obtained average somewhat over 100 acres, with about 85 acres of crops. Cotton is the chief money crop, and in many instances practically the only crop sold.

The hill land is sandy clay loam, or sometimes gravelly loam. The type of soil found in the little branch bottoms which are common on many farms is usually silt or clay loam.

Farms in this area are operated by the farmer and his family alone or with the help of a hired man or share cropper. On many farms negro labor is used for part of the year. In general, the upland farms are operated by the farm family with the help of negroes.

SUMMARY OF RESULTS.

To make easy any comparison between the various crops, labor requirements per acre are summarized in one table (Table I). Reference to the detailed tables further on will show that the labor requirements as given here do not represent precisely the full time spent by these men on their crops, but are simply the aggregate of man and mule labor requirements of those standard operations which are performed by all of the farmers.

The reliability of these figures depends partly upon the number of records considered and partly upon the uniformity or lack of uniformity of practices of individual farmers. Where there are a large number of records, lack of uniformity is neutralized. The number of records each on intertilled cowpeas, peanuts (first crop),

and sugar cane is less than 50, yet these figures are considered reliable, because the general practice followed in producing these crops is uniform. The number of records on broadcast cowpeas or peanuts after oats is not sufficient for a very reliable average, though they are believed to give a pretty fair indication of the labor requirements of these crops.

TABLE I.—*Summary of total average requirements per acre for various crops.*

Crop.	Hours per acre.		Number of reports.	Crop.	Hours per acre.		Number of reports.
	Man.	Mule.			Man.	Mule.	
Cotton.....	100.3	41.5	191	Cowpeas (cultivated).....	32.9	25.6	34
Corn.....	37.0	34.4	198	Cowpeas (uncultivated).....	16.6	23.7	10
Peanuts (first crop).....	57.8	45.6	36	Oats (for grain).....	21.7	24.1	30
Peanuts (after oats).....	43.9	36.4	14	Oats (for hay).....	16.7	20.8	21
Sweet potatoes.....	136.9	83.9	53	Meadow hay (native).....	17.1	19.4	50
Sugar cane.....	417.8	195.0	25				

Table II summarizes data for the operations performed on the various crops. The figures are taken from the various tables throughout the bulletin and represent in each case the implement, size, and crew in most common use.

TABLE II.—*Summary of operations, implements, crews, and acreages reported most frequently by hill farmers of Louisiana (677 reports).*

Operation.	Implement or method.	Size.	Furrows.	Men.	Mules.	Acres per day.
Cutting stalks.....	By hand.....			1		3.65
Do.....	Stalk cutter.....	1 row.....		1	2	7.75
Flat breaking.....	Walking plow.....	10 inches.....		1	2	1.65
Do.....	do.....	12 inches.....		1	2	2.11
Laying off rows.....	Shovel cultivator.....	4-foot row.....		1	1	7.46
Breaking middles.....	Middle buster.....	do.....		1	2	7.74
Do.....	Shovel cultivator.....	3-foot row.....	1	1	1	7.18
Bedding.....	Middle buster.....	3½-foot row.....	1	1	2	6.69
Do.....	Turn plow.....	do.....	2	1	1	3.52
Do.....	do.....	4-foot row.....	2	1	2	3.96
Do.....	do.....	3½-foot row.....	4	1	1	1.64
Do.....	do.....	4-foot row.....	6	1	1	1.18
Rebedding.....	do.....	do.....	2	1	1	3.88
Do.....	do.....	do.....	4	1	1	1.88
Broadcast harrowing.....	Disk.....	6 to 8 feet.....		1	2	5.43
Do.....	do.....	do.....		1	4	11.64
Do.....	Spike tooth.....	8 feet.....		1	2	12.00
Do.....	Log.....	7½ feet.....		1	2	12.50
Harrowing beds.....	Spike tooth.....	4 feet.....		1	1	7.87
Do.....	do.....	do.....		1	2	8.11
Do.....	Log.....	6 feet.....		1	1	13.07
Do.....	do.....	6½ feet.....		1	2	13.49
Do.....	A harrow.....	3½-foot row.....		1	1	6.98
Do.....	Shovel cultivator.....	do.....		1	1	7.06
Planting cotton.....	Planter.....	1 row.....		1	1	6.85
Scraping cotton.....	Scrape.....	3½-foot row.....	2	1	2	3.34
Chopping cotton.....	do.....	do.....		1		.97
Hoing cotton.....	do.....	do.....		1		1.38
Cultivating cotton.....	Cultivator.....	do.....	1	1		6.75
Do.....	do.....	do.....	2	1	1	3.48
Cultivating cotton middles.....	do.....	do.....		1	1	6.97
Planting corn.....	By hand.....	4-foot row.....		1		7.45
Do.....	Planter.....	1 row.....		1	1	7.42
Covering corn.....	By hand.....	4-foot row.....		1		8.00
Barring off corn.....	Turn plow.....	do.....	2	1	1	3.77
Cultivating corn.....	Cultivator.....	do.....	1	1	1	7.89
Do.....	do.....	do.....	1	1	2	7.17

TABLE II.—Summary of operations, implements, crews, and acreages reported most frequently by hill farmers of Louisiana (677 reports)—Continued.

Operation.	Implement or method.	Size.	Fur-rows.	Men.	Mules.	Acres per day.
Cultivating corn.....	Cultivator	4-foot row	2	1	1	3.82
Cultivating corn middles.....	do.	do.	1	1	1	7.56
Do.....	do.	do.	2	1	2	3.81
Thinning corn.....	By hand	do.	1	1	1	2.39
Hoeing corn.....	do.	do.	1	1	1	2.08
Planting peas in corn.....	do.	do.	1	1	1	7.18
Do.....	do.	Broadcast	1	1	1	15.53
Do.....	Planter	1 row	1	1	1	7.55
Pull and pile corn.....	By hand	do.	1	1	1	3.43
Haul corn from pile.....	Wagon	do.	2	2	2	7.52
Pull and haul corn.....	do.	do.	3	2	2	6.58
Planting peanuts.....	By hand	3-foot row	1	1	1	3.81
Cover peanuts.....	Turn plow	do.	1	1	1	5.91
Hoeing peanuts.....	By hand	do.	1	1	1	1.20
Cultivating peanuts.....	Cultivator	do.	2	1	1	2.88
Pulling peanuts.....	By hand	2-foot row	1	1	1	1.08
Shocking peanuts.....	do.	do.	1	1	1	1.62
Stacking peanuts.....	do.	do.	1	1	1	1.63
Drop sweet potatoes.....	do.	3½-foot row	1	1	1	1.13
Set sweet potatoes.....	do.	do.	1	1	1	1.04
Bar off sweet potatoes.....	Turn plow	do.	2	1	1	3.16
Cultivating sweet potatoes.....	Shovel cultivator	do.	2	1	1	3.14
Hoeing sweet potatoes.....	By hand	do.	1	1	1	.74
Cutting sweet potato vines.....	do.	do.	1	1	1	.93
Drag sweet potatoes.....	Turn plow	3-4-foot row	1	1	1	2.79
Plow up sweet potatoes.....	Middle buster	3½-foot row	1	1	2	4.57
Picking up sweet potatoes.....	By hand	do.	1	1	1	.42
Cultivate sugar cane.....	Shovel cultivator	5-foot row	2	1	1	4.75
Hoeing sugar cane.....	By hand	do.	1	1	1	.65
Planting cow peas.....	do.	Broadcast	1	1	1	13.50
Do.....	Planter	1 row	1	1	1	5.69
Mowing cow peas.....	Mower	4½ feet	1	1	1	6.23
Raking cow peas.....	Rake	9 feet	1	2	1	14.83
Planting oats.....	By hand	Broadcast	1	1	1	14.11
Mowing oats.....	Mower	4½ feet	1	1	1	7.60
Cutting oats.....	By hand	do.	1	1	1	3.24
Binding oats.....	do.	do.	1	1	1	3.33
Shocking oats.....	do.	do.	1	1	1	7.06
Mowing hay.....	Mower	4½ feet	1	1	1	5.83
Raking hay.....	Rake	10 feet	1	1	1	12.65
Picking cotton.....	By hand	a 636	1	1	1	b 130
Making cane sirup.....	Crusher and vat	do.	3	2	2	c 73.2

a Average pounds seed cotton per acre.

b Pounds seed cotton per day.

c Gallons per day.

SIGNIFICANCE OF CREW DUTY AND LABOR REQUIREMENTS.

The term "crew" as used here, means the number of men, or men and mules, required to perform an operation. Crews vary in size from one man, or one man and one horse, to several of each. The word "duty" as used here means normal performance, that is, what is actually done under normal conditions, rather than what should or could be done. "Crew duty," then, means the usual amount of work a crew can do in one day at a given operation. It is a normal day's work. For example, if a man hoes on the average an acre of cotton per day, his duty is here given as 1 acre. If a man and team break 2 acres of land per day, then the crew duty for such a crew is 2 acres. If a man uses a four-horse team and hauls 3 cords of wood per day, then the duty for this crew is 3 cords.

There are many factors affecting crew duty, such as stumps, size of fields, topography, ditches, kind of soil, size of mules, character of labor, and climatic conditions. Stumps are perhaps the greatest

hindrance in plowing and cultivating. Where stumps are numerous it is impossible to do a normal day's work. Small fields interfere very much with all kinds of mule work, because such fields usually have short rows which entail a great deal of turning and consequent loss of time. Terraces and ditches also interfere with field work because they often necessitate short rows. Heavy clay soils retard certain operations, particularly that of breaking. On the other hand, where the opposite of these conditions obtains, work will proceed more rapidly than on the average.

The extremes of such conditions on certain farms result in wide variations from the normal, but the influence of all such factors is neutralized to a large extent when a large number of records are considered for a given crop or operation. It is believed that the number of estimates here presented is large enough on most operations to give a reliable average. It will be noted in the tables showing crew duty that the acreages most frequently reported for any one operation, and the number of farmers so reporting, is given. Thus the average acreage may be compared with the acreage most frequently reported. When the number of estimates is not large enough, the statements made regarding the figures involved are qualified.

In the study of tables showing crew duty, it should be borne in mind that all the tables show, incidentally, the duty of machinery and implements as well as the duty of crews.

Labor requirements per acre.—The amount of labor required per acre to perform a given operation depends, of course, upon the crew duty for that operation. Therefore, knowing the duty of crews, it is easy to determine the labor requirement per acre (expressed in days or fractions of days) for each operation which may be performed, and also the average total amount of labor per acre actually spent on the principal operations. It is especially important to know the latter figure in order better to estimate the amount of labor (number of laborers) necessary to handle the crops which it is desired to grow; or, on the other hand, to adjust acreages so that labor requirements for all crops grown will not be beyond the capacity of the available labor on the farm.

SOIL PREPARATION.

Crew duty at preparing land for various crops may be considered without regard to the crop to be grown, because preparation work, in so far as crew duty is concerned, is similar for all crops. Therefore, since preparation work easily lends itself to a separate discussion, crew duty at such work will be dealt with before taking up the discussion of crew duty at such operations as planting, cultivating, and harvesting on each crop. Treating preparation separately makes available a larger number of estimates than if preparation were con-

sidered under each crop heading. Where crew duty is shown for such operations as bedding, harrowing, or dragging beds and laying off rows, the width of the rows is given. At such work the width of the row is the important thing to be considered in determining crew duty.

Stalks are usually cut on all land intended for cotton. Stalk cutting may, therefore, include the cutting of both corn and cotton stalks. The average width of all rows from which stalks are cut is 4 feet. (See Table III.)



FIG. 1.—One man and one mule breaking sod land, followed by a 3-foot disk drawn by two mules.

TABLE III.—*Cutting cotton and corn stalks.*

Method.	Number of reports.	Average acreage per day.	Acreage reported most frequently.
By hand.....	11	3.65	4 (5 reports).
1-row stalk cutter (1 man and 2 mules).....	109	7.75	8 (62 reports).

Breaking follows stalk cutting on all land previously planted to cotton or corn. Most of the reports show this operation as being done by one man and two mules. Where plows of a size smaller than 8 inches are used, the work is done by one man and one mule. (see fig.1.) No figures are given for this size of crew, owing to the small number of reports. (See Table IV.)

TABLE IV.—*Flat breaking with 10 and 12 inch turn plows (one man and two mules).*

Size of plow (inches).	Number of reports.	Average acreage per day.	Acreage reported most frequently.
10	64	1.65	1½ (36 reports).
12	65	2.11	2 (39 reports).

Broadcast harrowing is not very generally practiced in this area. However, enough reports were obtained to give an idea of what has been accomplished by different crews and implements. (See Table V.)



FIG. 2.—Bedding for cotton on land planted to the same crop the previous year. In this instance, contrary to common practice, the stalks have not been cut.

TABLE V.—*Broadcast harrowing.*

Implement.	Size.	Crew.		Number of reports.	Average acreage per day.	Acreage reported most frequently.
		Men.	Mules.			
Disk harrow.....	6, 7, and 8 feet.....	1	2	16	5.43	4 (5 reports).
Do.....	do.....	1	4	15	11.64	Scattering.
Spike-tooth harrow..	5 to 12 feet; average 8 feet...	1	2	36	12.00	12 (6 reports).
Log.....	5 to 12 feet; average 7½ feet..	1	2	24	12.50	11 (8 reports). 12 (11 reports).

“Bedding” and “listing” are common terms used in this area for ridging land in preparation for planting. “Bedding” is the term in most general use. Land is nearly always bedded for cotton and a good many follow this practice in preparing land for corn. Bedding is done

with a turning plow by throwing 2, 4, or 6 furrows together. (see fig. 2.) A lister or "middle buster" forms a bed by going once to the row and is in general use. (See Table VI.)

TABLE VI.—*Bedding.*

Implement.	Width of row.	Number of furrows.	Crew.		Number of reports.	Average acreage per day.	Acreage reported most frequently.
			Men.	Mules.			
Middle buster.....	3 feet.....	1	1	2	14	5.92	6 (11 reports).
Do.....	3½ feet.....	1	1	2	26	6.69	7 (14 reports).
Do.....	4 feet.....	1	1	2	23	7.39	8 (19 reports).
Turnplow.....	3 feet.....	2	1	1	10	2.84	3 (6 reports).
Do.....	3½ feet.....	2	1	1	21	3.52	3½ (10 reports).
Do.....	4 feet.....	2	1	1	20	3.67	4 (13 reports).
Do.....	3½ feet.....	2	1	2	12	3.41	3½ (6 reports).
Do.....	4 feet.....	2	1	2	16	3.96	4 (8 reports).
Do.....	3 feet.....	4	1	1	23	1.53	1½ (20 reports).
Do.....	3½ feet.....	4	1	1	88	1.64	1½ (40 reports).
Do.....	4 feet.....	4	1	1	80	1.93	2 (57 reports).
Do.....	4½ feet.....	4	1	1	10	2.05	2 (7 reports).
Do.....	4 feet.....	6	1	1	10	1.18	Scattering.

In a number of cases rebedding is practiced. This may be done for any of several reasons, namely, further stirring of the soil, throwing up a bigger ridge, and covering seed or fertilizer. It will be noted that the acreage per day varies slightly from that of bedding. (See Table VII.)

TABLE VII.—*Rebedding with turnplow—one man and one mule.*

Width of rows.	Number of furrows.	Number of reports.	Average acreage per day.	Acreage reported most frequently.
3 feet.....	2	11	2.86	3 (8 reports).
3½ feet.....	2	34	3.43	3½ (19 reports).
4 feet.....	2	48	3.88	4 (37 reports).
4½ feet.....	2	10	4.14	4 (6 reports).
3½ feet.....	4	21	1.71	1½ (10 reports).
4 feet.....	4	26	1.88	2 (19 reports).

Some form the bed by throwing two furrows together with a turning plow and then breaking out the middle with a middle buster or shovel, going once to the row. (See Table VIII.)

TABLE VIII.—*Breaking middles—one furrow.*

Implement.	Width of row.	Crew.		Number of reports.	Average acreage per day.	Acreage reported most frequently.
		Men.	Mules.			
Middle buster.....	3½ feet.....	1	2	17	7.00	7 (9 reports).
Do.....	4 feet.....	1	2	24	7.74	8 (15 reports).
Shovel cultivator.....	3 feet.....	1	1	10	6.08	6 (5 reports).
Do.....	3½ feet.....	1	1	22	7.18	7 (12 reports).
Do.....	4 feet.....	1	1	21	7.52	8 (13 reports).

Laying off rows (figure 3) is an operation requiring one trip to the row, usually with a one-mule implement. (See Table IX.)

TABLE IX.—*Lay-off rows with shovel cultivator—one man and one mule.*

Width of row.	Number of reports.	Average acreage per day.	Acreage reported most frequently.
2½ feet.....	12	4.91	5 (8 reports).
3 feet.....	27	5.95	6 (22 reports).
3½ feet.....	83	6.67	7 (46 reports).
4 feet.....	96	7.46	8 (57 reports).
4½ feet.....	12	7.75	8 (6 report).



FIG. 3.—One man and one mule laying off rows with a single shovel cultivator. The man in the background is planting in the rows already made.

Harrowing or dragging beds is an operation performed on practically every farm, because cotton and sweet potatoes are always planted on beds, and, frequently, both corn and peanuts. After the beds are formed it is a common practice to harrow or drag them to improve the seed bed. Sometimes a harrow or drag is wide enough to drag two beds at a time. A few perform this operation for sweet potatoes with a hand rake. However, there are not a sufficient number of estimates to give a reliable average for this method. (See Table X.)

TABLE X.—*Harrowing beds.*

Implement.	Width of row.	Crew.		Number of reports.	Average acreage per day.	Acreage reported most frequently.
		Men.	Mules.			
Spike-tooth harrow.....	4 feet.....	1	1	16	7.87	8 (12 reports).
Do.....	4 feet.....	1	2	17	8.11	8 (6 reports).
Do.....	Avg. 8 feet.....	1	2	15	13.30	14 (6 reports).
Log.....	Avg. 6 feet.....	1	1	26	13.07	12 (8 reports).
Do.....	Avg. 6½ feet.....	1	2	36	13.49	14 (6 reports).
A harrow.....	Avg. 3½ feet.....	1	1	99	6.98	12 (12 reports).
Shovel cultivator.....	Avg. 3¼ feet.....	1	1	72	7.06	14 (3 reports).
						16 (33 reports).
						8 (31 reports).
						16 (26 reports).
						8 (22 reports).

Commercial fertilizer is applied sometimes before planting and sometimes after, and occasionally both before and after planting. Perhaps the most common practice is to distribute the fertilizer and bed on it, then plant. Ordinarily only one application is made, about 200 pounds per acre. (See Table XI).

TABLE XI.—*Fertilizing before and after planting.*

Method.	Width of row.	Crew.		Number of reports.	Average acreage per day.	Acreage reported most frequently.
		Men.	Mules.			
By hand.....	3½ feet.....	1	.....	31	5.66	5 (5 reports).
Do.....	4 feet.....	1	.....	23	5.86	6 (11 reports).
Do.....	4½ feet.....	1	.....	10	6.16	6 (8 reports).
Distributor.....	3 feet.....	1	1	23	5.42	6 (5 reports).
Do.....	3½ feet.....	1	1	72	6.61	5 (9 reports).
Do.....	4 feet.....	1	1	99	7.25	6 (13 reports).
Do.....	4½ feet.....	1	1	14	7.31	6 (29 reports).
Do.....	5 feet.....	1	1	12	8.33	7 (34 reports).
Do.....	6 feet.....	1	1	10	9.11	7 (22 reports).
						8 (39 reports).
						8 (6 reports).
						Scattering.
						Do.

OPERATIONS ON INDIVIDUAL CROPS.

The crops most commonly grown in this region are cotton, corn, sweet potatoes, and cowpeas. These four crops are grown by nearly every farmer. Most farmers, however, grow other crops also, though the acreage is generally small. Thus, in addition to the above-mentioned staple crops, the farmer may grow oats or meadow hay as feed crops, and sometimes sorghum or peanuts. A few make sorghum sirup for market, and in certain communities peanuts are grown to a considerable extent for the market. On some of these farms sugar cane is grown for sirup. All of this sirup, except what is needed for home consumption, is sold. Occasionally watermelons are grown in small areas. Cotton is the only money crop of consequence generally grown. Occasionally a farmer will grow native

meadow hay as a money crop. Sweet potatoes are grown primarily for home use, but when there is a surplus it usually is for sale.

In the following pages each crop is considered separately. Under each of the crops crew duty and labor requirements per acre are given. Under crew duty, where a sufficient number of reports were obtained to give reliable averages, a table is presented for each crop, showing the labor requirement per acre for each separate operation from the beginning of preparation of the land until the crop is marketed.

COTTON.

Crew duty at preparation work having been shown, the first operation to be considered under each crop is planting. Cotton is nearly always planted with a planter, although it is sometimes planted by hand. However, all the records at hand for this operation are for planter work. (See Table XII.)

TABLE XII.—*Planting cotton with 1-row planter—one man, one mule.*

Width of row.	Number of reports.	Average acreage per day.	Acreage reported most frequently.
3 feet.....	12	5.95	6 (11 reports).
3½ feet.....	96	6.83	7 (46 reports).
4 feet.....	74	7.50	{ 7 (20 reports). 8 (39 reports).

In determining crew duty at cultivating operations, such work has been divided into three or four classes for each crop. "Scraping" is one of these. This is an operation performed on cotton before hoeing. This work is done with a one-mule implement which is run at a slight depth and throws the weeds and grass away from the row into the middles, thus cleaning the side of the bed or row and reducing its width preparatory to thinning or hoeing the crop. "Barring off" is an operation which applies more particularly to corn and sugar cane, although cotton is sometimes barred off. This is usually done with a one-mule turning plow, and the purpose is the same as that in scraping—that is, to throw weeds and grass to the middles and reduce the width of the bed to be hoed. This operation is usually followed by hoeing. (See Table XIII.)

TABLE XIII.—*Scraping cotton—one man, two mules, 2 furrows.*

Width of row.	Number of reports.	Average acreage per day.	Acreage reported most frequently.
3½ feet.....	57	3.34	{ 3 (22 reports). 3½ (22 reports).
4 feet.....	31	3.62	4 (14 reports).

The first hoe work on cotton is generally spoken of as "chopping." Chopping means chopping to a stand or thinning out. (see fig. 4.) Subsequent hoe work is usually spoken of as "hoeing." Hoeing is an operation primarily intended for removing grass rather than for thinning to a stand. (See Table XIV.)



FIG. 4.—Negroes chopping cotton. The plants when they come up are too close together, and are thinned out to the proper distance with a hoe.

TABLE XIV.—*Chopping and hoeing cotton—one man.*

	Width of row.	Number of reports.	Average acreage per day.	Acreage reported most frequently.
First time.....	3 feet....	12	0.82	1 (6 reports).
Do.....	3½ feet....	97	.97	1 (47 reports).
Do.....	4 feet....	76	.99	1 (43 reports).
Second time.....	3 feet....	12	1.18	1 (5 reports).
Do.....	3½ feet....	82	1.38	1½ (35 reports).
Do.....	4 feet....	63	1.40	1 (18 reports).
Third time.....	3½ feet....	13	1.38	1½ (21 reports).
				1 (9 reports).

Crew duty at cultivating has been separated according to the method employed, for some begin to cultivate without previously scraping, while others cultivate after scraping.

Cultivating middles has been considered separately from other cultivating, because there is nothing to interfere with this work, as

in cultivating the row. The operation of cultivating middles, or breaking middles, is one which may require from one to three furrows with a single plow or one-horse harrow. However, in Table XV, where this operation appears, all middle work is one furrow or single trip to the row.

TABLE XV.—*Cultivating cotton with single plow or harrow.*

	Width of row.	Crew.		Number of reports.	Average acreage per day.	Acreage reported most frequently.
		Men.	Mules.			
Cultivating cotton without scraping:						
1 furrow.....	3½ feet.....	1	1	10	6.75	Scattering.
Do.....	4 feet.....	1	1	10	7.80	8 (9 reports).
Do.....	do.....	1	2	10	6.85	6 (5 reports).
2 furrows.....	3½ feet.....	1	1	40	3.48	3½ (23 reports).
Do.....	4 feet.....	1	1	34	3.35	4 (24 reports).
Cultivating following scraping:						
2 furrows.....	3½ feet.....	1	1	54	3.33	3 (18 reports).
Do.....	4 feet.....	1	1	32	3.70	3½ (21 reports).
Cultivating middles:						
1 furrow.....	3 feet.....	1	1	10	6.00	4 (17 reports).
Do.....	3½ feet.....	1	1	70	6.97	6 (10 reports).
Do.....	4 feet.....	1	1	45	7.28	6 (22 reports).
						7 (29 reports).
						7 (6 reports).
						8 (28 reports).

The first operation in harvesting the cotton crop is picking. The records available on this work indicate that on the average an adult will pick 130 pounds per day in cotton averaging 636 pounds of seed cotton per acre. Most individuals can easily pick more than this, but when the work of a large number of pickers (men and women, but no children) is averaged for the whole picking season, it is found that 130 pounds is a normal day's work. There are many individuals who can easily pick 250 to 300 pounds per day, but the average of even these pickers for the whole season is far below such figures. High averages are made by individuals only during the first picking or by working long hours. Many pickers do not work full days on account of heavy dews in the morning.

HAULING COTTON.

Hauling to the gin is the second operation in harvesting the cotton crop. (See Table XVI.) In many instances hauling to the gin and marketing can not be separated, because the gin patronized is located in the town where the crop is sold. The cotton may be sold at the gin yard or hauled immediately after ginning to a near-by merchant or cotton buyer, thus saving a trip to town for the purpose of selling the crop. A large part of the time required for hauling cotton to the gin is consumed in waiting one's turn at the gin. (See fig. 5.) In marketing, a considerable amount of time is spent in seeking the highest bidder, weighing the cotton, and settling accounts.

TABLE XVI.—*Hauling cotton—one man and two mules.*

	Length of haul.	Bales per day.	Number of reports.	Number of bales per day most frequently reported.
Hauling to gin.....	Less than 1 mile.....	2.24	33	2 (17 reports).
Do.....	1 to 2 miles.....	1.94	35	2 (26 reports).
Do.....	2 to 3 miles.....	1.77	31	2 (24 reports).
Do.....	3 to 4 miles.....	1.68	22	1 (8 reports).
Do.....	4 to 5 miles.....	1.00	8	2 (13 reports).
Do.....	5 to 10 miles.....	1.45	11	1 (8 reports).
Hauling to gin and market.....	1 to 2 miles.....	2.00	10	Do.
Do.....	2 to 3 miles.....	1.66	10	2 (10 reports).
Do.....	4 to 5 miles.....	1.08	12	2 (6 reports).
Hauling to market.....	Less than 1 mile.....	2.50	8	1 (11 reports).
Do.....	1 to 2 miles.....	2.74	12	2 (5 reports).
Do.....	3 to 4 miles.....	2.37	8	2 (6 reports).
Do.....	5 to 6 miles.....	2.72	18	Do.
Do.....	7 to 8 miles.....	2.70	10	2 (12 reports).
Do.....	9 to 10 miles.....	2.37	9	2 (6 reports).
				2 (5 reports).

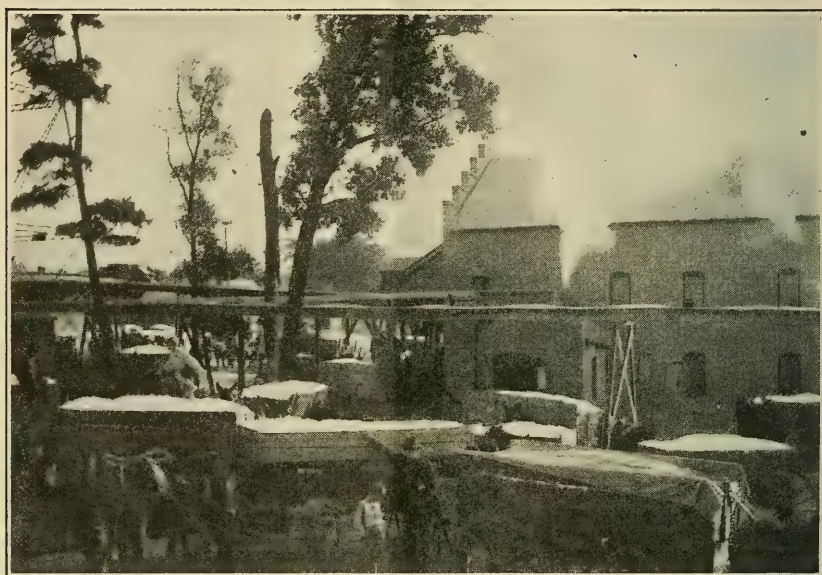


FIG. 5.—Cotton gin, showing a large number of men waiting their turn at the gin. Much time is lost in this way.

LABOR REQUIREMENTS OF COTTON.

The man and mule labor requirements of cotton by operations—that is, the amount of man and mule labor required when all of the operations are performed, are shown in Table XVII.

To determine by this table the amount of labor per acre required on cotton for a given farm, simply foot the figures for the operations performed on that farm.

It will be noticed that the greater part of the man labor is required for picking, the next largest for hoe work, and the next for culti-

vating. Man labor varies with the yield because picking is the slowest operation of all.

TABLE XVII.—*Labor requirements per acre of cotton, by operations.*

Operations.	Average hours per acre.		Number of reports.	Operations.	Average hours per acre.		Number of reports.
	Man.	Mule.			Man.	Mule.	
Cut stalks.....	1.7	2.4	54	Scrape.....	2.9	3.0	104
Break.....	6.3	12.1	46	Chop and hoe (average 2 times).....	20.0	-----	191
Broadcast harrow.....	1.8	5.2	24	Cultivate (average 4 times).....	13.8	14.6	191
Lay-off rows.....	1.5	1.6	88	Cultivate middles (average 2 times).....	3.6	3.7	138
Bed.....	4.4	5.3	185	Pick.....	46.7	-----	191
Rebed.....	4.1	4.7	97	Haul to gin and market..	2.7	5.4	182
Break middles.....	1.5	2.1	65	Market.....	1.9	3.9	73
Fertilize.....	1.6	1.4	135				
Harrow or drag beds.....	1.3	1.6	164				
Plant.....	1.4	1.4	191				

CORN.

Corn planting as a whole is more rapid than cotton planting, partly because the rows are wider, and partly because less time is lost in refilling the planter. Planting by hand is considerably slower than planting with a planter, as there is the extra work of covering the seed, which requires in itself as much time as planting with a planter. (See Table XVIII.)

TABLE XVIII.—*Planting corn.*

Method.	Width of row.	Crew.		Number of records.	Average acreage per day.	Acreage reported most frequently.
		Men.	Mules.			
By hand.....	3½ feet.....	1	-----	21	6.85	7 (13 reports).
Do.....	4 feet.....	1	-----	48	7.45	8 (28 reports).
Do.....	4½ feet.....	1	-----	11	7.72	8 (5 reports).
One-row planter.....	3½ feet.....	1	1	12	6.75	7 (6 reports).
Do.....	4 feet.....	1	1	57	7.42	8 (38 reports).
Do.....	4½ feet.....	1	1	14	8.07	8 (9 reports).
Do.....	5 feet.....	1	1	12	9.66	10 (6 reports).
Do.....	6 feet.....	1	1	11	10.27	12 (5 reports).

TABLE XIX.—*Covering corn after planting with shovel cultivator or turnplow: one man, one mule, and one furrow.*

Width of row.	Number of reports.	Average acreage per day.	Acreage reported most frequently.
3½ feet.....	20	7.10	7 (12 reports).
4 feet.....	46	8.00	8 (29 reports).
4½ feet.....	10	8.22	8 (6 reports).

Crew duty at the various operations in cultivating corn is shown in Tables XX to XXIII. The duty per day with cultivators at first cultivation and subsequent cultivations is practically the same.

Sometimes corn is harrowed broadcast with a section harrow before cultivating, but the number of farmers who do this is so small that no figures for this operation are presented. It will be noted that the rate of work in cultivating corn middles is practically the same as for the like operation on cotton.

TABLE XX.—*Crew duty at barring off corn with turnplow—two furrows, one man, and one mule.*

Width of row.	Number of reports.	Average acreage per day.	Acreage reported most frequently.
3½ feet.....	16	3.40	3 (6 reports).
4 feet.....	24	3.77	3½ (7 reports).
4½ feet.....	10	4.11	4 (16 reports).
			4 (5 reports).

TABLE XXI.—*Cultivating corn before and after barring off—one man, one mule, two furrows.*

Width of row.	Number of reports.	Average acreage per day.	Acreage reported most frequently.
3½ feet.....	19	3.39	3 (7 reports).
4 feet.....	26	4.08	3½ (8 reports).
4½ feet.....	10	4.11	4 (16 reports).
			4 (5 reports).

TABLE XXII.—*Cultivating corn without barring off.*

	Width of row.	Number of reports.	Crew.		Average acreage per day.	Acreage reported most frequently.
			Man.	Mules.		
1 furrow.....	4 feet.....	19	1	1	7.89	8 (14 reports).
Do.....	do.....	17	1	2	7.17	7 (5 reports).
2 furrows.....	3½ feet.....	15	1	1	3.63	8 (7 reports).
Do.....	4 feet.....	70	1	1	3.82	3½ (9 reports).
Do.....	4½ feet.....	12	1	1	4.08	4 (40 reports).
Do.....	5 feet.....	11	1	1	4.68	4 (6 reports).
Do.....	6 feet.....	10	1	1	4.94	5 (6 reports).
						Scattering.

TABLE XXIII.—*Cultivating corn middles.*

	Width of row.	Crew.		Number of reports.	Average acreage per day.	Acreage reported most frequently.
		Man.	Mules.			
1 furrow.....	3½ feet.....	1	1	25	6.96	7 (14 reports).
Do.....	4 feet.....	1	1	72	7.56	6 (6 reports).
Do.....	4½ feet.....	1	1	12	8.33	7 (12 reports).
2 furrows.....	4 feet.....	1	2	22	3.81	8 (49 reports).
						4 (6 reports).
						4 (15 reports).

In this area corn is frequently gone over twice with the hoe, the first time for the purpose of thinning and the second time for the purpose of hoeing out weeds and grass.

TABLE XXIV.—*Thinning and hoeing corn—one man.*

	Width of row.	Number of reports.	Average acreage per day.	Acreage reported most frequently.
Thinning.....	3½ feet.....	13	1. 80	2 (8 reports).
Do.....	4 feet.....	44	2. 39	2 (13 reports).
Do.....	4½ feet.....	10	2. 50	3 (10 reports).
Hoeing.....	3½ feet.....	13	1. 57	Scattering.
Do.....	4 feet.....	43	2. 08	1 (6 reports).
Do.....	4½ feet.....	14	2. 44	2 (10 reports).
				3 (11 reports).
				3 (10 reports).
				Scattering.

About half of the farmers of this area sow cowpeas broadcast in corn at "laying-by" time or plant them in rows either during the



FIG. 6.—Cowpeas planted in rows growing in corn. By planting peas in this way the land is enriched and extra feed obtained for stock.

cultivating period or at laying-by time. (See fig. 6.) Row planting may be done by hand or with a planter. Some plant peas in rows and others sow them broadcast. (See Table XXV.)

TABLE XXV.—*Planting peas in corn.*

Method.	Width of row.	Crew.		Number of reports.	Average acreage per day.	Acreage reported most frequently.
		Men.	Mules.			
By hand in rows.....	3½ feet.....	1		15	6. 23	7 (5 reports).
Do.....	4 feet.....	1		44	7. 18	8 (25 reports).
Do.....	4½ feet.....	1		10	6. 80	8 (5 reports).
By hand broadcast.....	4 feet.....	1		15	15. 53	15 (7 reports).
1-row planter.....	do.....	1	1	10	7. 55	Scattering.

In this area practically the only method of harvesting corn is to snap the ears from the stalks without shucking, which is usually referred to as "pulling corn." Some pull and throw the corn on the ground in small heaps and later pick it up and haul it in. Others pull the corn and throw it into a wagon direct, and as soon as a load is pulled it is hauled to the barn. In cases in which corn is pulled and thrown on the ground one man has been counted as a crew. Crews of from one to three men are generally used when hauling in corn which has been thrown on the ground, and crews of two or three men are most commonly used for pulling and hauling. (See Table XXVI.) A few four-men crews were found, but the number of such crews is not sufficient to give a reliable average.

TABLE XXVI.—*Harvesting corn.*

Method.	Bushels per acre.	Crew.		Number of reports.	Average acreage per day.	Acreage reported most frequently.
		Men.	Mules.			
Pull and throw in piles.....	11 to 20	1	.....	54	3.43	3 (16 reports). 5 (8 reports).
Do.....	21 to 40	1	.....	10	2.55	
Haul from piles.....	11 to 20	1	2	10	4.82	Scattering. 7 (8 reports).
Do.....	11 to 20	2	2	33	7.52	8 (7 reports).
Do.....	11 to 20	3	2	15	8.95	Scattering.
Pull and haul.....	11 to 20	2	2	11	5.72	6 (5 reports).
Do.....	11 to 20	3	2	60	6.58	5 to 8 (31 reports).
Do.....	21 to 40	3	2	28	4.78	4 to 5 (14 reports).

LABOR REQUIREMENTS OF CORN.

The amount of labor required at each operation in the production of corn is shown in Table XXVII. It will be noticed that much of the work on corn is one-mule work. This is indicated by the fact that man labor and mule labor are practically the same. The term "gather" as used in this table includes pulling and hauling corn from the field to the barn; it also includes pulling and throwing on the ground and then hauling in, and thus it is a term which includes more than the term "pulling." "Gather" is commonly used in this area to cover all the operations of harvesting. Cutting corn is an operation which is very seldom performed in this area.

TABLE XXVII.—*Labor requirements per acre on corn.*

Operation.	Hours per acre.		Number of reports.	Operation.	Hours per acre.		Number of reports.
	Men.	Mules.			Men.	Mules.	
Cut stalks.....	1.4	2.4	52	Plant.....	1.9	1.3	198
Break.....	6.2	11.9	72	Cover corn.....	1.3	1.3	79
Broadcast harrow.....	1.5	3.6	30	Fertilize after planting.....	1.6	.9	60
Lay off rows.....	1.4	1.5	128	Bar off.....	2.8	2.8	61
Bed.....	4.7	5.5	169	Cultivate.....	10.5	9.9	193
Rebed.....	3.6	4.1	81	Cultivate middles.....	3.6	3.7	156
Break middles.....	1.3	1.9	54	Thin and hoe.....	6.3	.....	160
Harrow.....	1.7	3.4	87	Plant peas.....	1.3	.4	127
Fertilize before planting..	1.6	1.0	68	Gather.....	5.7	3.5	198

PEANUTS.

Planters are not in common use for planting peanuts, chiefly because of the necessity of shelling the peanuts before they can be planted with a planter. As with corn planted by hand, the peanuts must be covered. This extra amount of labor no doubt makes it more profitable to use a planter for this operation, even though the labor of shelling is involved. When the peanuts were planted in 3-foot rows it was found that it would require the labor of one man and a mule, with a shovel cultivator or turn plow turning one furrow, to cover an average of 5.9 acres per day. (See Table XXVIII.)

TABLE XXVIII.—*Planting peanuts by hand after oats and as a first crop—one man.*

Width of row.	Number of reports.	Average acreage per day.	Acreage reported most frequently.
2½ feet.....	11	3.05	Scattering. Do.
3 feet.....	19	3.81	

The cultivating operations for peanuts are barring off, harrowing the rows, cultivating, and cultivating middles. Not enough reports were obtained to give reliable averages for any operation except cultivating. (See Table XXIX.)

TABLE XXIX.—*Cultivating peanuts after oats and as a first crop—one man, one mule, and two furrows.*

Width of row.	Number of reports.	Average acreage per day.	Acreage reported most frequently.
2½ feet.....	12	2.45	2½ (5 reports).
3 feet.....	18	2.88	3 (14 reports).
3½ feet.....	10	3.30	Scattering.

According to all estimates obtained on hoeing peanuts, one man will hoe 1.2 acres with rows 3 feet apart. This crop is hoed only once.

There are several methods of harvesting peanuts. The most common practice is to pull the vines by hand, then shock them. Some plow them up or loosen them with a plow, after which they are shocked. After the shocks have cured for from 3 to 6 weeks, the crop is hauled to the barn or thrasher. Some feed the entire plant, including the nuts. Where peanuts are thrashed, it is quite common to bale the vines or hay after they have passed through the thrasher. Some, instead of harvesting the entire crop, cut the tops off with a mowing machine and rake the hay, thus saving a hay crop only. When this is done, the common practice is to turn hogs into the field for the purpose of harvesting the peanuts. (See Table XXX.)

TABLE XXX.—*Harvesting peanuts.*

Operation.	Width of row.	Number of reports.	Average acreage per day.	Acreage reported most frequently.
Pulling up peanuts.....	2 feet.....	18	1.08	1 (9 reports).
(1 man).....	2½ feet.....	10	1.44	1 (5 reports).
Shocking (1 man).....		18	1.62	Do.
Stacking (1 man).....		13	1.63	Do.
Hauling to barn:				
2 men and 2 mules.....		15	5.03	4 (5 reports).
3 men and 2 mules.....		10	6.33	Scattering.

LABOR REQUIREMENTS OF PEANUTS.

The labor required at each operation on peanuts grown either as a first crop or as a second crop after oats is shown in Table XXXI. Preparation of the land for this crop is similar to that for cotton or corn. Harvesting operations require somewhat more work than corn harvest, but less than cotton harvest. When grown as a second crop after oats, peanuts require less labor than when grown as a first crop, because they are planted later and require fewer cultivations.

TABLE XXXI.—*Labor requirements per acre of peanuts, by operations.*

Operation.	Peanuts as first crop.			Peanuts after oats.		
	Hours per acre.		Number of reports.	Hours per acre.		Number of reports.
	Man.	Mule.		Man.	Mule.	
Break.....	6.4	12.3	15	6.3	12.7	5
Harrow.....	2.2	5.6	21			
Do.....				1.2	1.8	6
Bed.....	4.8	5.5	23			
Rebed.....	3.9	4.8	15			
Break middles.....	2.0	1.5	14			
Center furrow.....	1.9	1.9	28	1.8	1.8	12
Plant.....	3.2	1.9	36	2.8		14
Cover.....	1.6	1.6	23	3.0	3.2	12
Cultivate (average two times).....	9.5	9.9	36	6.3	7.2	14
Cultivate middles.....	2.4	2.4	12			
Hoe.....	10.7		23			
Plow up.....	2.2	2.9	13	2.1	3.9	4
Pull up.....	10.7		29	8.8		9
Shock.....	9.9		13			
Haul.....	6.3	6.3	32	5.2	6.0	13
Stack.....	8.4		11			
Thrash.....	6.0	2.6	15	5.0	4.0	4
Market.....	2.6	5.2	14	3.6	5.9	4

SWEET POTATOES.

In planting sweet potatoes there are really three operations—pulling the plants, dropping in rows, and setting out. (See Table XXXII.) There were not a sufficient number of estimates on pulling to give a reliable average.

TABLE XXXII.—*Dropping and setting sweet potato plants.*

	Width of row.	Number of reports.	Average acreage per day.	Acreage reported most frequently.
Dropping (1 man).....	{ 3 feet....	20	1.30	1 (8 reports).
	{ 3½ feet....	24	1.13	1 (11 reports).
Setting (1 man).....	{ 3 feet....	20	1.17	1 (8 reports).
	{ 3½ feet....	24	1.04	1 (12 reports).

The various operations in cultivating sweet potatoes, with crew duty at each, are shown in Table XXXIII.

TABLE XXXIII.—*Cultivating sweet potatoes.*

Operation.	Width of row.	Number of reports.	Average acreage per day.	Acreage reported most frequently.
Barring off with turn plow (2 furrows, 1 man and 1 mule).	{ 3 feet....	10	3.00	3 (10 reports).
	{ 3½ feet....	12	3.16	3 (6 reports).
Cultivating (2 furrows, 1 man and 1 mule).....	{ 3 feet....	41	3.00	3 (11 reports).
	{ 3½ feet....	21	3.14	Do.
Hoeing (1 man).....	{ 3 feet....	16	.70	0.5 (7 reports).
	{ 3½ feet....	15	.74	Do.

Turning vines is an operation which is necessary when it is desired to cultivate the crop after the vines have reached considerable length. Otherwise, the plow would break and tear away many of them. No figures are presented for this operation, however, as the number reporting was not large enough to give a reliable average.

Some method of removing the vines is usually employed before plowing up sweet potatoes. They may be cut and raked off or they may be dragged off. Potatoes are generally plowed up with a middle buster. However, some growers still use the turning plow, going twice or four times to the row. (See Table XXXIV.) There are so few who market potatoes in this area that no figures for this operation are given.

TABLE XXXIV.—*Harvesting sweet potatoes.*

Operation.	Width of row.	Number of reports.	Average acreage per day.	Acreage reported most frequently.
Cutting vines (1 man).....	3 to 4 feet.....	14	0.93	1 (7 reports).
Dragging vines, turn plow (1 man and 1 mule).	do.....	12	2.79	Scattering.
Plowing up, middle buster (1 man and 2 mules).....	{ 3 feet.....	13	4.38	4 (5 reports).
	{ 3½ feet.....	19	4.57	4 (5 reports).
Picking up (1 man) (average bushels per acre, 135).....		53	.42	6 (6 reports).
Hauling to barn (yield per acre):				0.33 (16 reports).
2 men and 2 mules 40 to 200 bu.....		23	1.62	0.50 (12 reports).
3 men and 2 mules 40 to 210 bu.....		13	1.87	Scattering.
				Do.

LABOR REQUIREMENTS OF SWEET POTATOES.

The sweet-potato crop requires more labor than cotton. The number of operations is large, and some of them, such as breaking and bedding, may be done two, three, or even four times before the plants are set out. This accounts for the large labor requirements for these operations as shown in Table XXXV. Planting, hoeing, and harvesting each requires a considerable amount of hand labor. The crop is usually hoed once.

TABLE XXXV.—*Labor requirements per acre on sweet potatoes, by operations.*

Operation.	Hours per acre.		Number of reports.	Operation.	Hours per acre.		Number of reports.
	Man.	Mule.			Man.	Mule.	
Break.....	14.4	10.0	40	Cultivate (average, 1½ times).....	8.1	8.3	49
Bed.....	7.5	8.0	51	Cultivate middles.....	2.8	2.8	29
Rebed.....	6.0	6.5	14	Hoe.....	19.7	.....	51
Drag beds.....	2.5	1.2	38	Cut vines.....	12.4	.....	15
Center furrow.....	1.7	1.7	14	Drag vines.....	3.6	4.5	26
Fertilize.....	3.2	2.4	22	Plow up.....	4.7	6.9	53
Drop plants.....	9.2	.....	53	Pick up.....	26.4	.....	53
Set plants.....	10.4	.....	53	Haul.....	21.0	15.6	52
Bar off.....	3.2	3.2	25				

SUGAR CANE.

With a limited number of records on sugar cane and the different-sized crews (2 men and 2 mules to 6 men and 2 mules), it was not possible to obtain enough estimates to give a reliable average on the planting operation.

Also in the harvesting operation, because of the variety of methods employed, there were not enough records obtained on any one to give reliable averages.

Table XXXVI presents the average crew duty at cultivating sugar cane.

TABLE XXXVI.—*Cultivating sugar cane.*

Method.	Width of row.	Number of reports.	Average acreage per day.	Acreage reported most frequently.
Cultivator (1 man, 1 mule, 2 furrows).....	5 feet....	10	4.75	5 (4 reports).
Hoeing (1 man).....	do.....	10	.65	0.5 (5 reports).

The crew duty at making sirup is shown in Table XXXVII. The crew duty as shown in this table includes all of the crew necessary for grinding the cane and evaporating the sirup.

TABLE XXXVII.—*Grinding cane.*

Gallons.	Crew.		Number of reports.	Average (gallons per day).	Number of gallons reported most frequently.
	Man.	Mule.			
40 to 100.....	3	2	10	73.2	75 (3 reports).
60 to 100.....	4	2	10	76.0	80 (4 reports).

LABOR REQUIREMENTS OF SUGAR CANE.

Sugar cane requires a very large amount of labor per acre, the amount at each operation being shown in Table XXXVIII. Planting, which includes digging seed cane from the beds where it was buried during the winter, hauling, laying in the rows, and covering, requires nearly 5 days' man labor and about 2 days' mule labor per acre. The heaviest labor demand of this crop is at harvest time. All of the operations from cutting to sirup making are slow when measured by the acreage covered per day.

Preparation of the land and cultivation do not differ materially in kind or amount from such work on cotton, except that cane hoeing is slower work than cotton hoeing. Furthermore, cane is nearly always hoed twice, and some hoe it three times. The increase in required labor comes chiefly at planting time and harvesting time.

TABLE XXXVIII.—*Labor requirements per acre of sugar cane, by operations.*

Operation.	Hours per acre.		Number of reports.	Operation.	Hours per acre.		Number of reports.
	Man.	Mule.			Man.	Mule.	
Break.....	6.8	10.4	9	Cultivate middles (average 2 times).....	7.7	7.9	16
Bed.....	7.7	9.8	19	Hoe (average 2 times).....	43.7	.....	25
Rebed.....	6.6	6.6	7	Strip and top.....	65.5	.....	15
Center furrow.....	1.2	1.2	9	Cut.....	26.6	.....	15
Fertilize.....	3.7	2.6	20	Haul.....	30.8	46.4	17
Plant.....	43.8	21.1	25	Grind and make sirup.....	126.5	61.6	25
Cover.....	3.0	3.0	14	Market.....	28.1	56.2	11
Baroff.....	2.8	2.8	17	Bed seed cane.....	27.1	3.3	11
Cultivate (average 3 times).....	16.4	16.4	25				

COWPEAS.

Cowpeas are planted both with planters in rows and broadcast by hand. (See fig. 7.) In the first case the crop is given some cultivation, while in the latter it is allowed to grow without any cultivation. The crew duty at planting is shown in Table XXXIX.

TABLE XXXIX.—*Planting cowpeas.*

Method.	Width of row.	Crew.		Num-ber of re-ports.	Average acres per day.	Acres reported most frequently.
		Men.	Mules.			
In rows:						
1-row planter.....	2½ feet.....	1	1	10	4.87	5 (5 reports).
Do.....	3 feet.....			13	5.69	6 (8 reports).
Broadcast:						
By hand.....	Broadcast.....	1		10	13.50	Scattering.



FIG. 7.—One man and one mule planting peas with a cotton planter. The rows have been previously laid out with a bulltongue.

About one man in three plants by hand. It will be noted that the rate of broadcasting by hand is considerably more per day than for planter work.

Cowpeas, whether planted in rows and intertilled or sown broadcast, are harvested in the same manner. Therefore, the duty of crews, at harvesting both the cultivated and the uncultivated crops, is shown in the same table (Table XL). This table shows acres cut per day with mowers of different widths. When one has a small acreage planted in rows and has no mowing machine, he sometimes cuts the vines by hand instead of hiring a mower. The men without mowers also rake the hay by hand. Hauling is most often done by two men and a team, though a three-man crew is used. Sometimes hauling is done by one man. The duty of these crews is shown in acres per day.

TABLE XL.—*Harvesting cowpeas, either intertilled or broadcast.*

Operation.	Width of implement.	Number of reports.	Average acreage per day.	Acreage reported most frequently.
Mowing:				
1 man and 1 mule.....	4½ feet.....	25	6.23	6 (7 reports).
Do.....	5 feet.....	10	6.99	7 (8 reports). Scattering.
Raking:				
1 man and 2 mules.....	8 feet.....	10	12.44	Do.
Do.....	9 feet.....	18	14.83	16 (10 reports).
Hauling to barn:				
2 men and 2 mules.....	.....	21	4.37	Scattering.
3 men and 2 mules.....	.....	15	5.16	Do.

LABOR REQUIREMENTS OF COWPEAS.

The labor requirements per acre on cowpeas are given in Table XLI. About half of the men planting peas prepare the land by breaking, harrowing, and laying off rows, while the others bed the and instead. Planting is done mostly with a planter. However, an extra trip is sometimes made to cover the seed. Cultivating amounts to only one-half day per acre.

TABLE XLI.—*Labor requirements per acre on cowpeas.*

Operation.	In rows intertilled.			Broadcast.		
	Hours per acre.		Number of reports.	Hours per acre.		Number of reports.
	Man.	Mule.		Man.	Mule.	
Break.....	6.7	10.6	17	7.5	9.7	9
Disk.....				2.2	7.6	4
Harrow.....	1.5	2.6	14			
Do.....				1.5	4.4	10
Lay off rows.....	2.2	2.6	15			
Bed.....	3.2	4.4	17			
Plant.....	1.9	1.6	34	1.0	.6	10
Cultivate.....	5.2	5.0	32			
Cultivate middles.....	2.1	2.1	10			
Cut.....	2.4	2.7	32	1.5	3.0	10
Rake.....	2.1	1.2	31	.7	1.4	10
Haul.....	5.4	5.5	30	4.8	4.5	10

OATS.

In this area oats are sown for grain and hay. The usual method of planting is by hand, some few using drills. Oats when sown by hand require covering afterwards. (See Table XLII.)

TABLE XLII.—*Planting oats for grain and hay by hand (1 man).*

Bushels per acre.	Number of reports.	Average acreage per day.	Acreage reported most frequently.
1½.....	16	12.50	Scattering.
2.....	17	14.11	12 (8 reports).

In this region oats are usually either cut by hand, bound and fed in the sheaf, or cut with a mower, raked, and fed as a hay crop. Oats are very seldom thrashed as a grain crop. Binders are very seldom used. (See Table XLIII.)

TABLE XLIII.—*Harvesting oats.*

	Crew.		Number of reports.	Average acreage per day.	Acreage reported most frequently.
	Men.	Mules.			
Mowing (4½-foot cut).....	1	1	10	7.60	Scattering.
Cutting by hand.....	1		25	3.24	3 (11 reports).
Binding by hand.....	1		24	3.33	3 (12 reports).
Shocking by hand.....	1		23	7.06	6 (8 reports).

The duty of two-men crews with a team, hauling oats, is shown in Table XLIV:

TABLE XLIV.—*Hauling oats for grain.*

	Number of reports.	Average acreage per day.	Acreage reported most frequently.
Yield per acre: 12 to 61 bushels.....	23	8.04	6 (5 reports). 10 (5 reports).
Hauling oats for hay to barn: ½ to 1½ tons.....	10	7.45	Scattering.

LABOR REQUIREMENTS OF OATS.

The labor required per acre on oats is shown in Table XLV. This table presents figures for operations at preparation work, seeding, and harvesting when the crop is handled either as a grain crop or as a hay crop. When oats are harvested as a grain crop, cutting and binding is usually done by hand. Up to the time of harvest there is no difference in the operations, hence the duplication of figures in the columns down to the time of cutting.

TABLE XLV.—*Labor requirements per acre for oats.*

Operation.	Oats for grain.			Oats for hay.		
	Hours per acre.		Number of reports.	Hours per acre.		Number of reports.
	Man.	Mule.		Man.	Mule.	
Cut stalks.....				1.2	2.4	8
Break.....	7.1	10.1	28	7.1	10.1	19
Disk.....				1.6	6.0	8
Harrow.....	1.1	2.0	17	1.1	2.0	18
Seed by hand.....	.7		26	.7		20
Cut by hand.....	3.3		25			
Cut with mower.....				2.4	1.3	21
Rake.....				.6	1.2	19
Bind.....	3.4		24			
Shock.....	1.4		24			
Haul.....	3.6	3.2	30	3.6	3.2	20

MEADOW HAY.

Meadow hay as found on these farms consists of native wild grasses sometimes mixed with a little lespedeza. The duty of a man and team at cutting and raking hay, with the most common width of implement in use, is shown in Table XLVI.

TABLE XLVI.—*Harvesting hay.*

	Width of implement.	Number of reports.	Average acreage per day.	Acreage reported most frequently.
Mowing, 1 man, 1 mule.....	4½ feet.....	27	5.83	5 (6 reports).
Raking, 1 man, 1 mule, twice over.....	10 feet.....	23	12.65	6 (7 reports). 12 (13 reports).

Other operations in hay harvesting are hauling loose hay from the field, baling, hauling baled hay, and marketing. Crew duty is given for the first operation only.

TABLE XLVII.—*Hauling hay from field (2 men, 2 mules).*

Yield per acre.	Number of reports.	Average acreage per day.	Acreage reported most frequently.
1 ton and less.....	13	4.07	4 (5 reports).
1½ to 2 tons.....	11	3.03	Scattering.

LABOR REQUIREMENTS OF HAY.

The labor required per acre for the various operations on meadow hay is shown in Table XLVIII. About three-fifths of those growing hay make two cuttings and about one-fifth make three cuttings.

TABLE XLVIII.—*Labor requirements per acre on meadow hay.*

Operation.	Hours per acre.		Number of reports.	Operation.	Hours per acre.		Number of reports.
	Man.	Mule.			Man.	Mule.	
First cutting.....	1.6	3.2	30	Haul.....	6.9	6.0	45
Second cutting.....	1.6	3.2	30	Press.....	10.0	2.9	23
Rake.....	1.6	3.2	30				

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WM. A. TAYLOR Chief



Washington, D. C.

PROFESSIONAL PAPER

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THE PRODUCTION OF THE EASTER LILY IN NORTHERN CLIMATES.

By DAVID GRIFFITHS, *Horticulturist, Office of Horticultural and Pomological Investigations.*

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THE CHOICE OF METHOD OF PROPAGATION.

IT IS ASSUMED that the grower of Easter lily stocks will start with seedlings. He may sow seed each season, but it is more likely that he will grow seedlings the first year and propagate vegetatively thereafter. When vegetative propagation is chosen the plants must be hardy enough to go through the winters safely out of doors. It has been amply demonstrated that the lily is sufficiently hardy in the latitude of Washington, D. C., to live through the winter either with or without a little mulch. The probability is that it will be found to be hardy very much farther north. If the grower goes back to seed each year it makes no difference whether the species is hardy in his locality or not, for the plants will not be in the open ground during the winter.

The stock plants may be of any standard commercial variety, or any two standard varieties may be crossed. Good results have been obtained by cross-pollinating the varieties Giganteum and Har-

risii, Giganteum and Formosum,¹ or even two plants of any one of the above varieties.

A grower will succeed more often by pollinating one plant on to the other than by using only one parent plant, or, in other words, selfing or pollinating a plant with its own pollen. It should be understood, however, that the basis of the stocks now grown by the Bureau of Plant Industry is selfed plants. But there was a deliberate purpose in view in starting in this way. The set of seed was uniformly small in nearly all of these selfs.

Pollination should be performed as soon as the stigma is receptive and the pollen ripe. This stage can be determined by watching the anthers as the flowers open. When the flower starts to open, the anthers will usually be found with simply a slight crack along one side, exposing a narrow line of dusty yellow pollen. After a time, which will vary with the light, temperature, and moisture conditions, the sides of this rupture will roll back, exposing the mass of dusty pollen over the entire surface of the anther. As soon as this condition is evident the pollen should be transferred to the stigma which is to be fertilized. The time which it will take from the gaping of the flower until the stigma is receptive, i. e., ready to be pollinated, will vary with atmospheric conditions. Under autumnal conditions in the greenhouse in cloudy weather it has taken 27 or 28 hours after the tube began to open before the stigma was receptive, while in the open in July flowers starting to open about sunrise were ready to be fertilized at 9 or 10 o'clock. The grower will have to determine this period quite definitely. In general, it can be said that the stigma is ready to receive pollen as soon as its surface becomes glossy on account of the secretion of a viscid fluid, which in this lily is about the time when the edges of the anthers have rolled back and completely exposed the yellow dusty pollen content. The sooner the pollination is done after these conditions obtain the better.

The Easter lily may be grown under wide extremes of conditions, but it is difficult under conditions which might be termed intermediate. It seems to be a safe crop when properly handled in the climate of either Washington, D. C., or the frostless Bermudas, but in the Gulf States it succumbs to the occasional low winter temperatures. This is not by any means without a parallel, the most striking one, possibly, being the hardiness of the Concord grape on the Great Lakes and its tenderness to frost conditions in Florida, and is readily explainable by the fact that farther north the plants are dormant during cold weather, while in the intermediate region they

¹ The botanical name of the Easter lily is *Lilium longiflorum*. The above names designate varieties which in commercial literature are usually referred to as here used without reference to their technical specific designation, *L. longiflorum*.

may be subjected to severe freezing weather when in full vegetative vigor.

There is evidence at hand that with care this lily may be grown much farther north in selected localities than has thus far been advised. There is little doubt that in those northern regions where the snowfall is heavy and early, even though the temperatures be very low, it can be safely grown in the open ground.

PRODUCTION ON A SEEDLING BASIS.

GROWING THE SEED.

Until such a time as the trade produces seed of the Easter lily and offers it for sale, it will be necessary for the grower to raise his own seed. The most feasible way to do this now is to procure imported bulbs either in the early winter, when they are generally offered for sale, or at Easter time, when most of the plants are in blossom, and grow seed for planting the following January.

To insure a good set of seed it is necessary to hand-pollinate each flower. (Fig. 1.) The blossoms are so large and their parts so conspicuous, that this is a simple and easy task. Seed may be produced in limited quantity without this trouble, but in the greenhouse, especially, the fertilization will be largely accidental and the set very poor or none at all.

If it is the florist's object to cross particular varieties, care should be exercised that no pollen except that which is wanted gets on the stigma. It will be necessary to remove the anthers from the flower to be fertilized before they open and spread their pollen. If the plant which has been pollinated is set 2 feet or so away from others which bear pollen, it is ordinarily safe from contamination in the greenhouse. Usually the florist is not interested in following up a line of breeding, and all that he needs to do is to see that plenty of pollen is put on the stigma at the proper time.

If pollinations are made at Easter, the seed will be ripe early in June. (Fig. 2.)

NECESSITY FOR HAND POLLINATION.

In the flower of the Easter lily the stigma is quite well isolated from the anthers. The action of the wind or other agency may cause the pollination of a flower with its own pollen, which, of course, is the closest kind of selfing. Also, it is possible, when plants are grown in the open, that cross-pollination at times may take place through the influence of insects and birds, but of this there seems to be little evidence. The necessity of hand pollination to obtain full fertilization consequently becomes apparent. Some seed will be obtained without any attention other than allowing the flowers to wither nat-

urally in the field, but a much better set can always be obtained by thorough artificial pollination.

SELFED COMPARED WITH CROSSED PROGENIES.

In the recent investigations made by the Bureau of Plant Industry no attempt was made to obtain excessive vigor in the stocks handled.



FIG. 1.—Pollinating the Easter lily. The parts of the flower are so large that even the conventional tweezers are dispensed with.

Some years ago Mr. George W. Oliver, working on this subject under departmental auspices, developed some remarkably vigorous progenies by crossing the two commercial strains, *Harrisii* and *Giganteum*.¹ Other investigators have obtained similar results by crossing

¹ Oliver, George W. The production of Easter lily bulbs in the United States. U. S. Dept. Agr., Bur. Plant Indus. Bul. 120, 24 pp., 4 pls. 1908.

the varieties *Multiflorum* and *Harrisii*. The progenies with which work has been done recently have as their basis selfed plants, i. e., those produced from the pollen of a plant used on its own stigma instead of on the stigma of another plant of the same or a different variety. Subsequently, cross-pollinations of plants in the same lots have been practiced for the most part.

Commonly, but not always, the set of seed in selfed plants is small as compared with that obtained when two plants of the same variety or of different varieties have been crossed.



FIG. 2.—A crop of Easter lily seed being produced in a greenhouse.

LONGEVITY OF THE SEED.

There is but little information as to the length of time that the seed of the Easter lily will remain viable after it is harvested. Experience has shown that if planted as soon as it is gathered it takes about twice as long to germinate as when held and planted 6 months later. Perfect germination has occurred when the seed was 18 months old. This shows that perfect results may be expected from seed held over to the second year. Whether seed can be safely held longer is not known. All the seed worked with in these investigations was stored in paper sacks in the packing shed of an ordinary greenhouse.

PLANTING THE SEED.

The time of planting seed will depend upon how the florist is going to handle his stocks, and possibly upon when his seed becomes available. Sowing can be done at any season if suitable moisture conditions for germination are maintained. If seed is planted out of doors, it should be sown in late autumn for spring germination.

For germination in flats, the usual compost of loam, sand, and leaf mold with a very little well-rotted manure is preferred. Good success has been obtained with a variety of potting soils, even with quite heavy clays ameliorated with a little sand and rubbish.

The best practice in sowing the seed is to fill the flat to the proper depth and strike the surface to a level. The seed is then scattered over this surface and pressed down rather firmly with a piece of board. The whole is then covered with one-eighth to one-fourth of an inch of fine soil sprinkled over the top. In out-of-door plantings it is better to put the seed three-fourths to 1 inch deep.

HANDLING THE SEED FLATS.

To the experienced plantsman the best direction that can be given on the subject of handling is "keep the flats in proper condition for germination." This condition does not differ for most seeds. Moisture should be kept at the surface constantly, but good provision for drainage should be made, so that the soil will never become water-logged.

If it is not possible to keep the surface properly moist without it, a pane of glass can be laid over each flat, but if the moisture conditions of the greenhouse are as they should be this is not necessary. It will be all the better not to have had the glass on when the plants begin to come through, for at this time, especially if the plantings are thick, moisture and aeration must be carefully watched lest damping-off occur.

The flats after germination are preferably kept rather dry. Watering should be copious, with provision for rapid drainage, but at comparatively infrequent intervals, so that the seedlings and the surface of the soil be not too wet. Clay seed pans can be used, in which case it will not be necessary to wet the young foliage at all for a time.

The time it takes for the seed to come up will vary greatly with conditions. The first lot of seed produced in these experiments ripened in June. It required six or seven weeks to germinate when sown immediately after being gathered. The same seed planted the following January came up in three weeks.

POTTING.

The exact stage of growth at which Easter lily seedlings should be potted may vary considerably. Usually it has been the practice

to transfer them to 2-inch pots when the second leaf was fairly well developed, although this has been done frequently when the first leaf was well straightened out. (Fig. 3.) It does not make much difference which practice is followed. At whatever stage they are transferred the plants seem to stand still for about three weeks after potting, and until the roots get out to the sides of the pot the top growth is always next to nothing; but after this the development is very rapid.



FIG. 3.—A flat of several lots of Easter lily seedlings ready to be potted.

TRANSPORTATION OF SEEDLINGS.

There is an opportunity for the development of a business in the production of 2-leaved or 3-leaved seedlings, to be furnished to florists or others to grow either in pots or in the open ground.

Such seedlings might be sold either directly from the seed flats or, after being established, from a first shift. The plants are as easily transported in the 1-leaved to 3-leaved stage as at any other time. They have been shipped from Washington, D. C., to California in mail packages several times, and have arrived in perfect condition. One trial package in fine condition when it reached California was re-wrapped immediately and returned, but as it was not sufficiently protected from the cold it froze on the return trip.

A successful method of packing is to lay down, first, a strip of paper, then on this a ribbon of moist sphagnum moss 2 or 3 inches wide. The seedlings are placed on the moss with the tops all one way

and extending beyond the sphagnum ribbon. They may be spread three or four or more deep, also in a ribbon, on the packing material. When all the seedling plants have been arranged and covered with a similar layer of sphagnum, the whole may be rolled up tight, the paper being tightly folded about the bottom and loosely folded around the top. The package should then be tied and packed in a strong container, so that it can not move. (Fig. 4.) Thus handled, the seedlings can be transported cheaply to any part of the country.

TRANSFER TO THE FIELD.

If the seed of the Easter lily is sown about the 1st of January and potted in early March the plants will be ready to go into the open



FIG. 4.—Easter lily seedlings in second leaf, showing the method of packing adopted for shipment by mail.

ground in late April or early May, or when they will be safe from any inclement weather. They are then knocked out of the pots and planted without disturbing the ball of earth. There seems to be no checking of growth, the plants taking hold of the ground with no loss of time.

When handled as stated, the 2-inch pots are well filled with roots by the time the plants go into the field. It is therefore possible to knock the plants out and carry them to the field in flats, from which they are set with a trowel.

CONDITIONS IN THE FIELD.

The experience of the Bureau of Plant Industry with these lilies has been restricted to a heavy retentive clay soil ameliorated by the use of some sand and plenty of very rough stable manure. None of these stocks have as yet been grown on sandy soil.

The seedlings have usually been set out in 3-foot beds 5 to 8 inches apart each way, which seems to afford ample space. Between the beds a 15-inch path has been left, which is also ample; a 12-inch path might be sufficient.

After planting, it is desirable to work a little mulch of some suitable material between the plants to assist in preventing the ground from baking, preserving moisture, and keeping the soil cool. For this purpose sand and spent manure from sweet-potato beds, old manure, and even fresh very strawy manure have been used. The care of these plantings during the summer has consisted in keeping down the weeds by hand and watering during dry weather. In well-prepared soil, mulched with some débris, hand weeding is not a serious matter.

DEVELOPMENT DURING THE SUMMER.

Lily plants set in the field from 2-inch pots in late April or early May will begin to throw up scattering stems in July, and some blossoms will appear late in the month. These early-flowering forms will be short, few flowered, and in general disappointing. As the season advances the stems become longer and bear a large number of flowers, but never are the plants in the field as tall as those in the greenhouse, although they often reach a height of 24 inches or more. When the time for frosts arrives there will be plenty of plants showing either flowers or buds to the number of three to seven, and in rare instances as many as a dozen. Possibly 25 per cent will have flowered, and the earliest will be maturing their seed, but most of the plants, nearly 75 per cent of them, will be in the form of large rosettes of basal leaves and plants which have started to form stems.

REPOTTING FROM THE FIELD.

Before there is danger of severe frosts in autumn the lily seedlings should be repotted for winter flowering. The minimum temperature to which they should be subjected out of doors is about 28° F.

The plants can be dug conveniently with a spading fork, ordinary care being used not to bruise them. (Fig. 5.) Most of the dirt is taken off the roots, and they are laid loosely in boxes, to be transferred to the packing shed. Here within three or four days they are put into the smallest-sized pots into which they will go. Most of them, though, will have to go into 6-inch pots, for the reason that on

account of the very large root system they can not be put low enough in pots of smaller size. There will be a goodly percentage of them, however, which can go into 4-inch and 5-inch pots. Whenever this is possible they should go into these small pots and be shifted to 6-inch pots when the smaller sizes are filled with roots.

LOSS OF LEAFAGE IN REPOTTING FROM THE FIELD.

It frequently happens that a goodly percentage of the bulbs, especially those which consist of the smallest number of basal leaves, lose all their leafage before they are placed in pots. No



FIG. 5.—Digging Easter lily seedlings in October, 1920. The seed was sown on November 1, 1919. The plants are to be potted for winter flowering. Those which have not already flowered will be potted with the tops on and will not wilt.

change in handling is necessitated by this loss, these bulbs being potted and treated precisely like the others.

A most remarkable thing is the subsequent loss of leafage by the plants as they grow in the greenhouse. Those plants which are in the form of rosettes when repotted will in a few weeks be seen to lose their lower leaves gradually, so that by Christmas there will be but little of the field leafage left. Of course, the leaves in this case are from bulb scales. The loss never simulates wilting or any other apparently unhealthy condition, but looks simply like a gradual ripening process.

This loss of leafage is by no means confined to the scale leaves. The same loss takes place in the stem leaves of those plants which were

in a more or less advanced stage of stem development when repotted. The lower leaves gradually ripen and dry up in the same way, often leaving naked a few inches of the stem at the surface of the pot. This leaf loss takes place even when the plants have not been subjected to frost in the field.

TRANSPORTATION OF NONDORMANT BULBS.

The loss of the leaves naturally leads to the question whether it will be possible to produce seedling stocks, such as described, and transport them in autumn a reasonable distance to be repotted and forced. Experience this year seems to indicate that this can be done. Bulbs which had lost all their leaves were repotted and came right along in good shape, although in some cases they were not potted for four days after digging. It would not be surprising if it should be found feasible to wrap the plants singly in paper in a butcher's package, even in the advanced rosette stage, and pack them tightly in boxes for shipment, but this has not yet been attempted.

It should be noted that this is very different from the transportation of dormant bulbs, although it may not at first seem very different, especially when the seedling bulbs have lost their leaves. The bulbs referred to here, however, are in what might be called a vegetative condition, in distinction from the imported bulb, which is dormant. The imported bulb has a well-developed crown ready to go on and function the next season. The seedlings set out in May and dug from the field in a vegetative condition in October have a crown also, but it is in process of growth and its growth will build up another crown for the next season's development about the time that the plant blossoms. The fact that the bulbs can lose all their leaves at potting time and still go on and function satisfactorily from the same crown seems to warrant the conclusion that they can be transported safely for moderate distances.

CARE AFTER REPOTTING.

The plants are repotted from the field in all stages of development, from a rosette of basal leaves only to plants in full bud. (Fig. 6.) All can be potted in the same way and handled alike afterwards. It has been the practice to keep the pots on the benches in the greenhouse without heat from the time of repotting in October as long as the night temperature does not go below 40° F. As soon as there is necessity for heat a temperature of 45° to 50° F. is maintained at night until early December and then increased to a maximum of 60° F. The plants continue to flower during this period and from this time forward.

HANDLING PLANTS THAT HAVE FLOWERED IN THE FIELD.

At digging time the early seedlings (fig. 7) which have already blossomed in the field should be separated from the others and the stems cut off, but they can be potted like those which have not flowered and made to flower again by Easter, thus giving one small and one normal crop of flowers in 18 months from seed. They require no different treatment from those which have not flowered. However, if the florist desires, he can plunge them outside or treat them in all respects like imported bulbs.



FIG. 6.—A group of seedlings of the Easter lily of the 1919 progeny, selected from the field in late autumn to show diversity in development. Photographed a few days after they were potted from the field. All are of the same age.

GROUPING SEEDLING STOCKS.

As the bulbs are potted from the field it is possible to segregate them into five or more groups. One group will be in full bud and will blossom within 10 days or two weeks. Another can be made to blossom for Thanksgiving, another for Christmas, another in February, and the last for Easter. The last group will include the most backward of the plants in the field which have not flowered, together with the early-flowering forms which are to blossom the second time. Of course, by holding them at different temperatures, all except those in bud, and possibly even those, can be made to blossom at the later date.

NATURE AND APPEARANCE OF THE SEEDLINGS REPOTTED FROM THE FIELD.

As will be noted from the statements made on previous pages, the seedlings at potting time are exceedingly variable, the greatest variation occurring in the time at which they flower first, but there are also great differences of form aside from mere stature. (See fig. 6.)

As has been stated, the early-flowering plants are short, 12 or 15 inches high, but those in full bud at repotting time are 2 to 2½ feet high and bear three to five flowers or more, while the first ones to open have one or two flowers as a rule.



FIG. 7.—Easter lily seedlings. Seed planted January 1, 1919; pricked off in March; set in the field May 1; blossomed in late July; photographed October 6, 1919. Two of the bulbs are double nosed; all are 6½ to 8 inches in circumference.

Below those showing buds there are plants in all stages of growth. Some have a few inches to a foot of stem with no buds showing, while others present a varying degree of basal leaf development with no signs of stem growth. It is in this late group, which has the most prolific development of basal leaves, that the grower will find the most robust plants and also the most floriferous ones. It is not at all uncommon for these, when the flower stem appears, to show very large ones bearing 8 to 15 flowers.

Of all the field stocks thus handled, the preference is for the late-flowering forms, which bear a luxuriant growth of basal leaves, forming a large rosette at the surface of the ground at repotting time.

These are invariably vigorous and productive. Each of these basal leaves in seedlings tips a bulb scale, and it is found that the plants which hold back and build up a large store by the development of an abundant strong basal leafage before throwing up their flower stalks are the strongest and most productive.

The plants which have blossomed in the field are exceedingly interesting from the fact that they bear mostly double-nosed bulbs, which when potted will give at the second blossoming two stems bearing two to five flowers each. (See fig. 7.) Why this preponderance of double-nosed bulbs occurs at this stage so prominently in field-grown seedlings is not entirely clear. The condition is more general than in pot-grown plants, i. e., those kept in pots in the greenhouse through their first flowering. It looks sometimes as though the stem in the field is of such great diameter as actually to force a separation of one side of the bulb from the other, thus compelling the formation of two crowns for the next season instead of one, as normally obtains in bulbs of the same size developed vegetatively from small bulbs.

BEHAVIOR OF THE SEEDLINGS AFTER REPOTTING FROM THE FIELD.

The methods of handling the seedlings after they are repotted from the field have been considered under another heading. Their behavior is most satisfactory. In two years' experience in handling them in this way they have never even appreciably wilted, although three or four days have sometimes elapsed between the time of digging and the end of the potting.

In the handling incident to the transfer from the field to the pots some and frequently all of the leaves are broken off, for the basal leaves of seedlings, attached as they are to the tips of the scales, are quite brittle. There is, consequently, a goodly number of the bulbs which are entirely without leafage when ready to pot. No attention is paid to this, these bulbs being potted like the others. They invariably come on again in fine condition from the same crown; in other words, they are not to be distinguished from the dormant imported bulbs except that they grow more rapidly.

Strange as it may seem, these repotted seedlings, although moved with care and wilting but little, have to make in large measure a new root system after being potted from the field. Plants at all stages of growth, even up to full well-advanced buds which will open in 10 days, can be successfully repotted, but even these make an almost entirely new root system.

For this reason it will not do to subject the plants to heat until the pots have filled with roots again, any more than it is permissible to subject poorly rooted imported bulbs to such treatment. This point should be kept in mind. The grower should realize that he can

not subject these vegetatively potted plants to heat at the same stage of top development as dormant potted bulbs. He should remember that these seedlings, which are all the way from large rosettes to plants in full bud and are perfectly "fit" in appearance, may have a great paucity of roots until new ones have had a chance to develop.

It is not intended to give the impression that all the roots on plants which come from the field rot off, but many, and probably most of them as a rule, and often all of them, do. In spite of this loss and the additional loss of leaves which may or may not accompany it, the plants seem to recover and continue to grow until they flower in a perfectly satisfactory manner.

What probably occurs is a rejuvenation or reestablishment of the uninjured roots and often of uninjured portions, all others decaying during the time that the plants are becoming established in the pots by the development of a new root system. There is need for careful investigation to determine to what extent the subsequent growth of plants would be injured by the complete removal of the root system when repotting them from the field while in vegetative condition.

In the care of this lily the imported bulbs always have their roots trimmed close, while an attempt is made with many lilies to save as much of the root system as is possible in handling.

It will probably be much better not to attempt to set a time limit on the period required for the lily plants to reroot at a temperature of 40° to 50° F. at night. It will be much safer for the grower to depend upon the condition of the root system, which is most accurately gauged by an examination of the plant knocked out of the pot. The same conditions should govern the application of heat here as with imported stocks, with which the grower is familiar.

TREATMENT OF SEEDLINGS NOT INTENDED FOR WINTER FLOWERING.

The previous discussion is based on the assumption that the lily seedlings are to be brought into the greenhouse for their first flowering, or in the case of the early ones for their second flowering, upon the advent of cold weather in late autumn. If the intention, on the other hand, is to carry them out of doors, it will be realized that the plants are at two decided disadvantages with reference to the approaching cold weather.

In the first place, all plants that have not flowered are going into the winter in full vegetative vigor and, in the second place, they are shallowly set on clean-tilled ground. Under such conditions in the climate of Washington, D. C., they may not winter successfully.

A very heavy mulch of coarse material, such as cornstalks, might protect the bulbs sufficiently, but it is believed to be much the better method of treatment to dig and reset them at the proper level before the ground freezes in the fall. The digging can be done either before

or after the tops are cut by freezing weather, but before there is danger of the ground freezing to any great extent. All the top growth should be cut off and the bulbs reset about 4 inches deep and mulched, preferably with an inch or two of manure, after the ground freezes a little. In the latitude of Washington, D. C., the digging and resetting can be done most advantageously about the 1st of November, when it is advised that dormant bulbs generally be planted. Handled in this way the seedlings will have a maximum period of development and will still have time to get a firm hold on the soil before winter sets in.

TREATMENT OF SEEDLINGS AFTER THEY HAVE FLOWERED IN THE GREENHOUSE.

The disposition made of the bulbs after flowering will depend entirely upon circumstances. If the florist sells potted plants, that, of course, is the end of the transaction. He will then produce more seed and raise a new crop of seedlings for each winter's flowering, as described in previous pages. If, as is more likely the case in all middle latitudes, he wishes to work up stocks of vegetatively propagated bulbs to be handled like imported stocks, it will be necessary to preserve the bulbs as his potted plants flower. In this case, the flowers can be cut with short stems for formal pieces, or even with a foot of stem cut. The pots should then be kept rather dry and allowed to dry up completely within a month or six weeks. Any time after the 1st of April, or before if the soil can be worked, the bulbs can be planted in the open ground.

The plants will blossom again in late July. In the fall they will be dug, the largest bulbs taken out for forcing or for sale, and the increase replanted in order to continue the outdoor growing.

PRODUCTION ON A VEGETATIVE BASIS.

PLANTING VEGETATIVELY PROPAGATED STOCKS.

The previous pages deal with seedling stocks up to the time they are ready to be propagated vegetatively, as the Easter lily is usually produced. If these same stocks are to be grown continuously the handling must, of course, be modified. Normally, the lily bulbs will be planted in late autumn; but if the first-year seedlings have been flowered in the greenhouse the bulbs will have to be planted out as soon as the ground can be worked in the spring.

The character of the field planting will probably resolve itself into a bed eventually, mainly on account of the advantage of a mulch, which becomes an excessive burden in any but the most intensive form of culture. No better method of planting can be recommended than the Dutch bed, in which the planted space is 3 feet wide, with a 12-inch to 15-inch path between the beds. The bulbs are planted seven to nine or more to the row across the bed. (Fig. 8.)

The bulbs should be separated into four or five sizes before planting. In spring plantings of the seedling bulbs out of the house, two sizes will probably be sufficient; for in this case the bulbs will be large, with very little, if any, propagation. They will be simply the large seedling bulbs. Assuming that the rows are uniformly 6 to 8 inches apart, the larger of these sizes can be planted about seven to the row and the smaller nine to the row. They should be uniformly spaced and set up. After the seedlings have been grown outside for a year, however, there will be a large propagation of bulblets, and consequently it will be better to make four or five sizes.



FIG. 8.—Bulbs being planted in a Dutch bed.

In starting the planting on the bed plan, it is necessary to line out the beds carefully with taut lines, marked off by running a spade down 2 or 3 inches along the line and scraping the soil toward the center of the bed from either side. The soil is then thrown out of the first bed to a depth of about 4 inches and the bottom raked to a level. The bulbs are then set and spaced, as already described. The soil from the opening of the second bed is used to cover the bulbs in the first, and so on to the end of the plat. Figure 8 shows this method of planting the narcissus on Puget Sound and illustrates the operation very well.

After the first year there will be more than two sizes, as there will be plenty of stem bulblets at the next digging. It will then be necessary to plant a larger number to the row. One may have 14 and 21

to the row set up, and another size strewn along the row about one to the inch. The latter should not be covered so deeply as the large bulbs.

A modification of the above method of planting which obviates the moving of so much soil has proved satisfactory. The ground is prepared as before and preferably floated or rolled. Rows are then opened up lengthwise of the bed with a wheel hoe having a plow attachment. A row is opened and planted, and then the second row is opened and the first covered by the same operation. Five or six of these rows 6 to 8 inches apart are planted; then a row is skipped for a path and the next bed started. Either of these forms of setting gives a thick planting, which it is believed is the most economical of space, labor, and materials.

TIME TO PLANT NORMAL VEGETATIVELY PROPAGATED STOCKS.

In vegetative propagation the time of planting will always be late autumn, though the date will vary with the locality. There are two important requirements that should be met. The bulbs should be well rooted before the ground gets so cold that no growth can take place. On the other hand, they should be planted so late that top growth will not take place before winter. The grower should endeavor to strike a balance between these two extremes, remembering that this lily does not stop growing so long as the moisture and temperature conditions are favorable. It is this characteristic that makes the crop a precarious one on portions of the Gulf coast, where suitable growing weather for it is likely to be interspersed with sudden drops of temperature which are severe enough to cut the top growth.

In the climate of Washington, D. C., the best time to plant is about the first of November. Even at this late date the plants sometimes come through in very open winters and are somewhat yellowed by subsequent cold weather in early spring, but no injury has been apparent thus far.

MULCHING.

The matter of a mulch is of sufficient importance to be treated separately; indeed, it has sometimes seemed that a mulch expressed the difference between success and a large measure of failure in growing these plants under field conditions.

The mulch serves a dual purpose. It is an adjunct to the fertilizer applied and a protective covering as well. The application should consist of an inch or two of manure. The material should be either fine or strawy and not cloddy, so as not to interfere with the plants coming through.

The application should be made in early winter after the ground has cooled off sufficiently so that growth is stopped, and it should remain during the growing season.

A summer mulch is considered as important in the culture of this lily as a winter one. Most lilies grow where there is a soil cover of some kind—many of them where this cover is a grassy one and others where the ground is just as effectively protected by brush, under and between which the lilies grow, sticking their heads above the canopy to flower.

Lilium longiflorum, with the forms of which we are dealing, produces a mass of roots from the stem above the bulb and near the surface of the ground. For the best results these roots, as well as those from the bulb, must have good conditions for development and must not be disturbed. This condition is admirably produced by a manure mulch, which not only furnishes plenty of fertility but prevents the soil from drying out and baking and also equalizes its temperature to a remarkable degree. One should keep in mind that this lily, like most other lilies, likes to have its feet moist and cool and protected both summer and winter, but its head must be in full light.

FLOWERING TIME FOR SEEDLINGS AND MATURE STOCKS.

Attention has been called in a general way to the irregular blossoming of a seedling generation. The experimental stocks in 1920, sown on November 1, 1919, began to flower in early July, at the same time as the out-of-door vegetatively propagated plants. The last of the progeny did not open its flowers before the end of May, 1921. All of these seedlings were kept under precisely the same conditions from the time of sowing the seed, and all operations, such as pricking off, potting, etc., were performed in as short a time as ordinarily would be possible. In spite of this identical handling, there was an extreme variation of 11 months in the time of flowering.

In all progenies which have been grown in the last six years the behavior has been similar. When, however, these same bulbs have been handled normally for vegetative stocks, i. e., planted in November, they have all flowered within a short space of time. (Fig. 9.) Two or three weeks cover the entire blossoming period, which is as close as would be the case with imported varieties grown out of doors in the same way.

THE CUT FLOWERS.

As in bulb culture, there is always a temptation to utilize the crop of flowers when there is sale for them. It has been found that it is practicable to cut off half of the stem in the first flowering of the seedlings in the greenhouse and still preserve the bulbs for starting vegetative propagation by planting out in the spring. The pots, after the cutting, are dried off rather quickly and the bulbs left in the soil until ready to plant out. There are no data on the comparative value of stocks thus flowered and those which have had their

tops cut off and planted at normal depths out of doors to flower the next year. The bulbs are without much doubt weakened by this cutting and quick drying off, but they blossom well again in late July in the field and appear to recuperate perfectly in one season.

In normal vegetative propagation the flowers in the field should be removed when in bud or shortly after they open. If there is a sale for them the individual flower stems 4 to 6 inches long may be safely taken off, in which case the blossoms can be utilized for formal pieces; but no leafage should be removed from the plants. If there is no object in letting the flowers open they can just as well, and more easily, be snapped off in late bud.



FIG. 9.—A block of about 1,500 mature bulbs of the Easter lily being seeded at the Arlington Experimental Farm, Va. In the foreground are seedlings of the current year. Photographed on July 7, 1920.

TIME TO HARVEST FALL-PLANTED STOCKS.

It must be frankly admitted that the best time to dig the bulbs of the Easter lily is not known. It is well known, however, that the period over which they may be dug and good results obtained is longer than with most bulbous plants.

With bulbous stocks generally the tops are allowed to die down before the plants are dug, but unless a severe drought occurs very few of these lilies will die before frost cuts them down in the fall. In a field planting nearly all the stems are in vegetative vigor when cold weather starts, though a few scattering stems may show signs of maturing.

Probably the best guide to the time of digging is the formation of the new crown for the next year's growth, but to the uninitiated this may be difficult to interpret properly. At times the abundant

formation of new roots, which appear in early September, has been the guide, and digging has been done when this occurs. This is probably to be looked upon as a reaction to more favorable temperatures for growth rather than an indication of maturity, but, nevertheless, stocks dug in early September, as the summer temperatures abate, have behaved perfectly under forcing and field conditions the next season. When dug at this season though, the bulbs must be looked upon as not fully mature and as comparable to much of the imported stock from Japan, which also is dug while in full vegetative vigor.

Digging has been done from September 10 to October 30. The performance of the bulbs dug during this period is about the same, so far as has been observed, but no careful comparative tests have been made.

When the bulbs are dug late there is commonly a small percentage of the stocks in which growth has started from the next season's crown. This growth is more likely to take place in the propagation than in the old bulbs. There is little doubt that there is in this characteristic a basis for selection, to which attention is now being given.

To sum up this matter, it can be said that the bulbs can be dug from September 10 to October 15 or 20 and that the late digging probably gives the best-matured bulbs, although those dug earlier apparently develop satisfactorily.

METHODS OF PROPAGATION.

Any plant to become widely useful must be able to make rapid increase. Lilies in general have been considered the aristocrats of the flower kingdom because of their beauty and the difficulties in producing them, but the Easter lily can be grown from seed so as to blossom in less than a year and can be produced vegetatively in one season. There are many methods of increasing the stock.

SEED.

Propagation by seed has been discussed in previous pages, and the method of handling has been fully described. Seed propagation gives clean stock and is a quick way of getting blossoming plants. It is also exceedingly desirable for various other reasons. It furnishes a quick and easy way to build up stocks from a few plants. It enables the small grower or the florist to produce his own forcing stocks and to get blossoms continuously from seven months after planting the seed up to and including the second Easter following the seeding. The method of propagation by seed is also very economical of time and effort, since the stocks may be carried out of doors for six months on a space practically equal to the size of the greenhouse required to

force them. Even in very cold regions where the plants will not stand the winter climate, florists can still produce their own flowering plants, for by this method of propagation the stocks are

flowered in the greenhouse during the winter, having made their development out of doors during the summer.

BULBLETS.

In the natural course of growing the plants, besides the bulb or bulblet planted, there is a propagation along the stem of from 1 to 30 bulblets which form in the axils of the leaf scales under the ground. (Fig. 10.) This is the most common method of propagation and is ample for continuing the stock and increasing it from year to year. These bulblets are taken off the stems at digging time and planted to continue the propagation. Commercial bulbs can be produced from the best of these in one year. They will not be so large as some com-



FIG. 10.—Two stems of the Easter lily, showing the different character of reproduction. On the right seven bulblets $2\frac{1}{2}$ to $3\frac{1}{2}$ inches have been produced; on the left are 20 bulblets 2 to $2\frac{1}{2}$ inches. The former is much the more desirable. Photographed late in October, 1920.

mercial stocks now imported, but they will produce better.

SCALES.

The bulbs may be broken up into their individual scales, which can be planted in the open ground 2 inches deep or in flats in the green-

house. Bulblets form on the cut end of the scale, as in most lilies. The scales may also be incubated in a moist atmosphere in summer: the growth of the bulblets then becomes very much accelerated. They may be handled almost exactly like hyacinths in propagation, except that if they are not covered they require an atmosphere somewhat more moist.



FIG. 11.—Propagation of the Easter lily by cuttings inserted in sand in a greenhouse. The results shown were obtained in about three months. *A*, a 4-leaf cutting in which three bulblets have developed; *B*, a cutting from the terminal portion of a nonflowering stem; *C*, the best of the bulblets found on the cuttings; *D*, a cutting from the terminal portion of a stem, showing bulblets formed above ground as well as below.

CUTTINGS.

Cuttings of side shoots and various portions of stems with three or more leaf scales stuck in moist sand will live and form bulblets in a surprisingly short time. Such cuttings, so far as is known, do not root, but bulblets form in the axils of their leaves and these soon strike root. Figure 11 shows this well. Such growth as is shown in this illustration can be made in three months or less.

LAYERING.

Old stems which have blossomed may be layered in moist sand or simply laid on the surface of the ground in a moist atmosphere. When this is done bulblets form readily along the lower part of the stem.

BULB DIVISION.

A natural propagation takes place in the Easter lily, as in nearly all other lilies, by the division of the bulb into two or more after it reaches maturity. After such a division it is necessary to plant the units out one year to round up, or they can be forced as double-nosed bulbs.

BEST METHODS OF PROPAGATION.

The most useful methods of propagating the Easter lily are by seed and bulblet formation, the latter being the most common and in middle latitudes the most practicable for the production of dormant bulbs.

At present it seems advisable for growers intending to produce dormant bulbs for sale to start their propagation from seed, because of the freedom from disease and the greater vigor and general cleanliness of such stocks when compared with abused imported bulbs.

CONTROLLING BULBLET FORMATION.

A very large measure of control can be exercised by the grower over the amount of propagation. If the stocks are set shallow there will be less propagation by far than if the planting be deeper. In heavy, poorly aerated soils, however, there is a limit to the efficacy of deep planting, as the formation of bulblets is mostly confined to the upper 3 or 4 inches of soil. This fact is well brought out in figure 12, in which the bulblet formation will be seen to take place in the well-aerated soil near the surface of the ground.

It is also feasible to increase the propagation by the addition of more mulch or by banking up around the plants with earth.

SOIL FOR EASTER LILIES.

The Bureau of Plant Industry is not in a position to discuss the subject of soil for Easter lilies very exhaustively, for the reason that its stocks up to this time have been grown on only one type of soil. It can be said with confidence, however, that a clay loam is well adapted to the plants.

The soil on which these stocks of Easter lilies have been grown is basically a heavy, lean, bakey clay. This has been ameliorated with some sand, liberal dressings of rough manure, and cover crops. The response to this treatment has been all that

could be expected. As stated elsewhere, the winter mulch has been left on during the summer, in order to prevent the soil from baking. Success has also been obtained with these lilies in a plastic clay fill, ameliorated with hard-coal ashes and rough organic debris.

SOIL FERTILITY.

The production of bulbs of the Easter lily is on a par with bulb production generally in so far as fertilizer requirements are concerned. The procedure is to have well-fertilized soil and crop it to its limit. Any one familiar with the root system of a well-developed Easter lily bulb knows that there is not much left in ordinary soil after a bulb has been grown in each 6-inch square. The plants are gross feeders and for good results must be supplied with an abundance of available plant food. A good market gardener's application of fertilizer will answer very well.

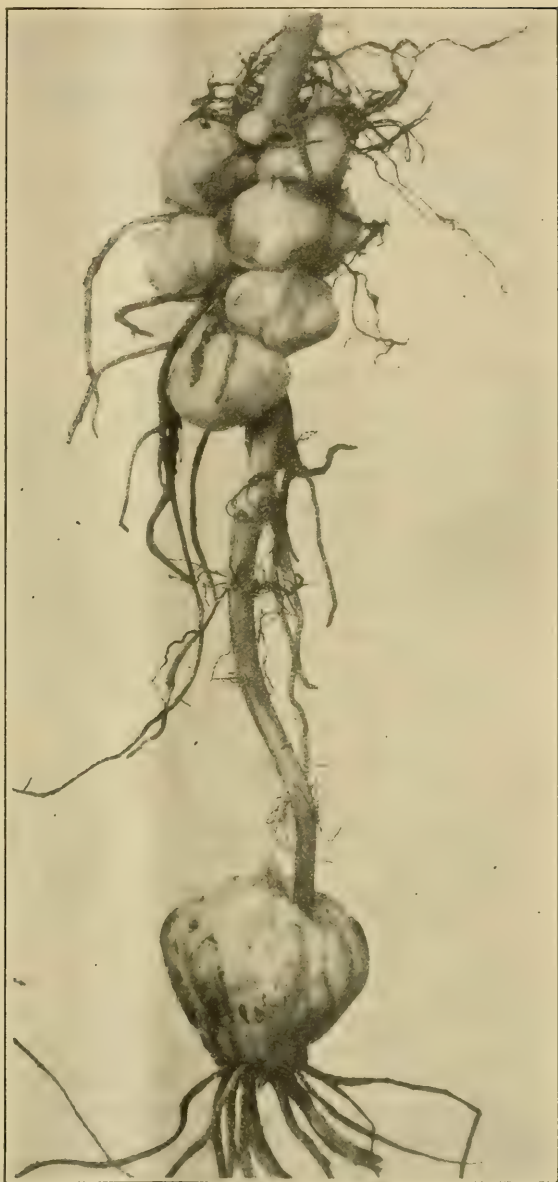


FIG. 12.—The underground parts of an Easter lily plant at digging time. The bulblet formation, it will be seen, is in the upper 3 or 4 inches of soil. Photographed from a plant set very deep, as was considered necessary in northern climates when these investigations were begun.

The fertilizer used will be that which is most available. As indicated above, the experimental culture described in these pages has been on poor soil fertilized with stable manure, and the ground has been covered with crops to turn under whenever the time during which it was not occupied would permit. Manures should be well incorporated and applied sufficiently in advance of planting to avoid the detrimental effects of raw fertilizers. Experience indicates that rots in the base of the bulbs are rather easily induced by carelessness in the use of manures.

STORAGE OF BULBS.

Bulbs of the Easter lily should be exposed to atmospheric influences as short a time as possible. Imported stocks are packed in pulverized dry earth as soon as possible after they are dug. In this pack the evil effect of a bulb mass is avoided, the bulbs are kept dry, and excessive desiccation is prevented.

Cold-storage handling has been developed to a high degree of perfection. The bulbs are held 2 degrees above the freezing point for a year, and in some cases for two years, and still they give results. They usually go into storage in the original pack.

The handling of home-grown stocks is, of course, a matter for experiment. There is much to learn about it. The temperature must be kept down, the atmosphere kept dry, and the ventilation controlled, so as to prevent the bulbs from wilting too much. These requirements are not difficult to fulfill in September or October in a reasonably well-arranged building which is dry. The light on the bulbs should also be subdued or they will turn green in a short time. It is particularly important that the atmosphere of the storage house be dry, because root action starts very quickly in a moist atmosphere and blue mold is likely to cause trouble. If the bulbs must be kept out of the ground longer than a month, or six weeks at most, they are better packed in pulverized dry earth, as are imported stocks.

Stocks of bulbs of the Easter lily have been carried by the Department of Agriculture on a basis not altogether ideal. The bulbs were out of the ground in 1920 from September 20 to November 1 and were somewhat wilted when planted, but not injuriously so. After digging they were worked over on the benches in a greenhouse, a very bad place. They were then stored in a poorly ventilated half basement which was only moderately dry.

It is not a difficult matter to hold the bulbs over winter in the climate of Washington, D. C. They have been carried over for spring planting in almost perfect condition when packed like imported bulbs in dry sand in boxes and buried in dry earth under a porch of a dwelling. The box was put down in the ground 1 foot

and had an added covering of another foot of dry leaves. These bulbs kept in good condition up to the 1st of May.

SIZES OF MERCHANTABLE BULBS.

Imported stocks of Easter lily bulbs range in size from 6 to 12 inches in circumference, the price charged being roughly proportional to the size of the bulb and indicating in a general way that there is merit in large size which is of advantage to the florist. There is a difference of opinion on this point, and some of the best growers use the smaller sizes.

Commonly, the prices quoted are the same per case for all sizes. In a recent quotation by one of the leading importers, five sizes of Formosums, running from 6 to 11 inches, are advertised at the same price per case; but the number of bulbs in the case varies from 100 for the large size to 350 for the smaller. Here there is a difference of $3\frac{1}{2}$ to 1 when the number of bulbs is considered.

It is believed that the yield from the successful culture of imported bulbs is somewhere between three and five flowers per plant for all sizes. There are no comparative records of the performance of different-sized bulbs available, but practical growers express satisfaction with the yield mentioned.

Investigations by the Bureau of Plant Industry are not yet extensive enough to warrant more than partial conclusions with reference to these matters, but the few records which have been made are very suggestive and seem to indicate that the performance of domestic stocks is superior to that of the imported bulbs; at least, results which are superior to those just mentioned are secured. This may be due to the better condition of the bulbs, owing to the short time during which the domestic stocks are out of the ground. It is not believed that the manner of handling accounts for the better behavior. Whatever be the cause, it has been possible to obtain an average yield of more than five flowers from bulbs only 5 to 6 inches in circumference, the smallest size that the florist uses, or smaller.

This in reality is a very important matter. It means that if satisfactory results can be secured under forcing conditions from domestic bulbs 5 to 7 inches in circumference, they can be produced abundantly in one year from stem bulblets. This is not less than a year shorter time than is at present required to produce bulbs in foreign countries.

It should be noted that the best of the stem bulblets will blossom the first year of independent existence and grow to forcing size. (Fig. 13.) In one test an average of more than two flowers per bulb was secured under forcing conditions from 110 selected bulblets, some producing five and six flowers. (Fig. 14.)

VARIETAL SELECTIONS.

But little has been accomplished in the segregation of uniform strains of Easter lilies. The seedlings are especially variable in form, and it is thought that selections based on individual performance will yield the best results. In seedlings in the vegetative condition upward of 30 more or less distinct types are recognizable. They have not been studied long enough to determine their relative qualities. This will take time.

The season at which distinctions in vegetative characters are most noticeable is that just preceding the formation of flower buds, strange as it may seem, but there are many characters which are quite pro-

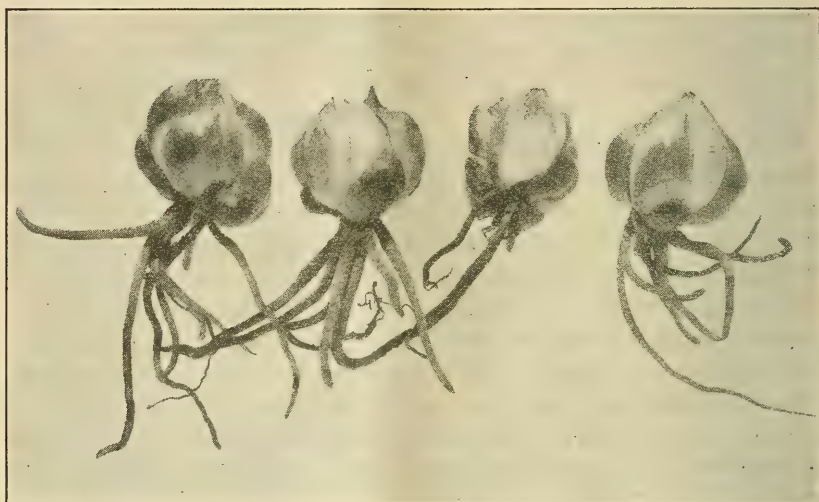


FIG. 13.—Four stem bulbets from a single stem, measuring $3\frac{1}{2}$ to 4 inches in circumference. These bulbets will be large enough to force after growing one year. This kind of reproduction is much more desirable than a larger number of smaller bulbets.

nounced even in the rosette stage. Selections can profitably be made before the buds show, and a reselection after the flowers open. It will probably be worth while also to make selections based on bulb characteristics.

Whether the early-flowered seedlings perpetuate the characteristic of early flowering in the vegetative progeny is not known. Some plants start into new growth early, i. e., the new crowns for the next year begin to grow even before the first flowers have faded. Fortunately, the percentage of these is small, and they probably should be eliminated. The desirable bulb is one that forms a large, promising crown for next year's performance which remains dormant during autumn if not disturbed.

Another aspect of the subject is the desirability of producing uniformity in seedlings, a much more difficult matter than to produce it in the vegetatively propagated progenies selected from these seedlings. This also is being attempted.

THE EASTER LILY IN BEDS AND BORDERS.

No lily is more satisfactory for beds and borders than the Easter lily. It is also well adapted in our middle latitudes for permanent plantings. In spite of what has been said in previous pages about the necessity of making plantings so late that no top growth will take place, in a permanent planting there is a wonderful adaptation,



FIG. 14.—A selected lot of 110 stem bulblets forced in order to determine their flowering qualities. The smallest are in the foreground. Three did not flower. The average for the entire lot was $2\frac{1}{2}$ flowers per plant, one producing six flowers.

and under ordinary conditions there is no more danger from forced early growth than with many other herbaceous perennials.

In permanent plantings the stems should be allowed to function until quite late in the autumn. If they do not die down naturally they can be allowed to grow until killed by frost. It is seldom cold enough for this, though, in the climate of Washington, D. C., before the regular time of planting, about November 1.

In permanent plantings it is advisable to allow the plants to set seed. Observations seem to show that the stem functions longer in autumn when a crop of seed is being produced than when the pods have been removed. The late functioning of the old stem retards activity in the next season's growth until the ground becomes too cold for top growth to take place.

Late in the season, say about November 1, it is desirable to go over the beds and loosen the soil around the stems, being careful not to interfere with the bulbs. After the soil is loosened a quick jerk will remove the stem and its bulblets, leaving the bulb in place for next season's growth. It is very desirable that this be done in order to prevent the plants from becoming too crowded. Instead of jerking the stem out of the bulb it may be cut off below the bulblets where the stem is bare. Deep planting—6 to 8 inches—is advisable for permanent plantings of this kind.

LENGTHENING THE FLOWER SEASON OUT OF DOORS.

Bulbs planted at the regular planting time, the 1st of November, will blossom in the climate of Washington, D. C., in early July. If the bulbs are held over and planted as soon as the ground can be worked in the spring they will blossom a month later, and seedlings grown from sowings made the 1st of January will begin to open about the same time as spring-planted bulbs. These will continue to flower until frost.

To get blossoms out of doors earlier than from normal stocks is a little more difficult, but still entirely possible. Bulbs can be put into 4-inch pots and set away at a temperature of 40° F. early in the year. They can be kept in frames and brought to varying degrees of development by spring, when they can be knocked out of the pots and set in the open. It will make no difference except to slow up their growth if the temperature goes below the freezing point for short periods a few times after the plants are well rooted. Handled in this way they can be brought to flower at least a month earlier than normal November planted stocks, thus giving blossoming plants out of doors from May until frost.

REDUCING THE COST OF HEAT IN FORCING.

By a little maneuvering, and this is always necessary in getting a batch of lilies in blossom for any particular date, methods can be worked out for flowering lilies with much less cost for fuel than now obtains with imported stock.

Seedlings potted from the field in October, in various stages of development, can be put into groups according to size and held in frames until the first of the year if wanted for Easter. The most advanced of them will need no heat until a later date, and from that time they can be kept much cooler than is usual with freshly potted bulbs.

It is suggested that it may be entirely feasible to carry bulbs in ordinary storage so far into the summer that when planted out they can be reotted for winter flowering in the field after as much as a

foot of stem has formed. With cold storage for a month or two, of course, this procedure would be possible.

It is thought that methods of timing stocks can be worked out for the warmer sections of California so that the plants can be brought into flower at almost any season with no artificial heat.

These possibilities, coupled with the further one of holding the cut flowers for two or three months in cold storage, suggest many modifications in handling and in supplying cut flowers for the market.

RESISTANCE TO COLD.

A light frost will not injure the Easter lily even when in flower. Plants in full flower and full bud have been known to withstand a temperature of 28° F. at night with no permanent injury. A temperature of 26° F., however, killed all the flowers and buds except a few barely in view and amply protected by the surrounding leaves. On the Gulf coast a drop from growing weather to 20° F. is considered fatal to plants in vegetative condition.

The six years' experience of the Bureau of Plant Industry has proved that this crop when properly handled is safely hardy in the climate of Washington, D. C. Proper handling means simply that the plants are set late, so as to insure dormancy during the winter. There are no data which enable one to judge just what the limiting temperatures are, but it has been amply demonstrated over a period of six years that the strains of the Easter lily worked with are hardy in the climate of Washington, where the normal minimum is 10° F. and the temperature commonly goes to zero at some time during the winter.

UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 963



Contribution from the Office of Farm Management and
Farm Economics

H. C. TAYLOR, Chief

In Cooperation with the Bureau of Plant Industry

W. A. TAYLOR, Chief



Washington, D. C.

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COST OF PRODUCING SUGAR BEETS IN UTAH AND IDAHO, 1918-1919.

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INTRODUCTION.

The data in this bulletin are based upon 220 farm estimates given by beet growers in five irrigated districts in Utah and Idaho—namely, Lehi, in Utah County, Utah; Garland, in Boxelder County, Utah; Idaho Falls, in Bonneville County, Idaho; Blackfoot, in Bingham County, Idaho; and Twin Falls, in Twin Falls County, Idaho. (Fig. 1.) The cost estimates obtained in the first four counties are for the year 1918. The records from the Twin Falls area are for 1919.

Special attention is given to a consideration of the basic factors of production. The hours of man labor and horse labor required in growing sugar beets do not vary greatly from year to year, and the pounds of seed used and the tons of manure applied remain fairly constant. Values, however, may fluctuate widely within a relatively short period; hence costs reported on a money basis solely have proved to be very unsatisfactory, especially when comparisons are involved and the results for two different periods are set up side

by side. The man-labor and horse-labor requirements are given by operations for each of the four districts. The total average labor requirement is also analyzed by districts.

The farms included in this study derive the major part of their receipts from crop enterprises. Live-stock receipts exceeded 20 per cent of the total farm receipts in one district only. In the Lehi and Garland districts the sugar beet was the outstanding crop

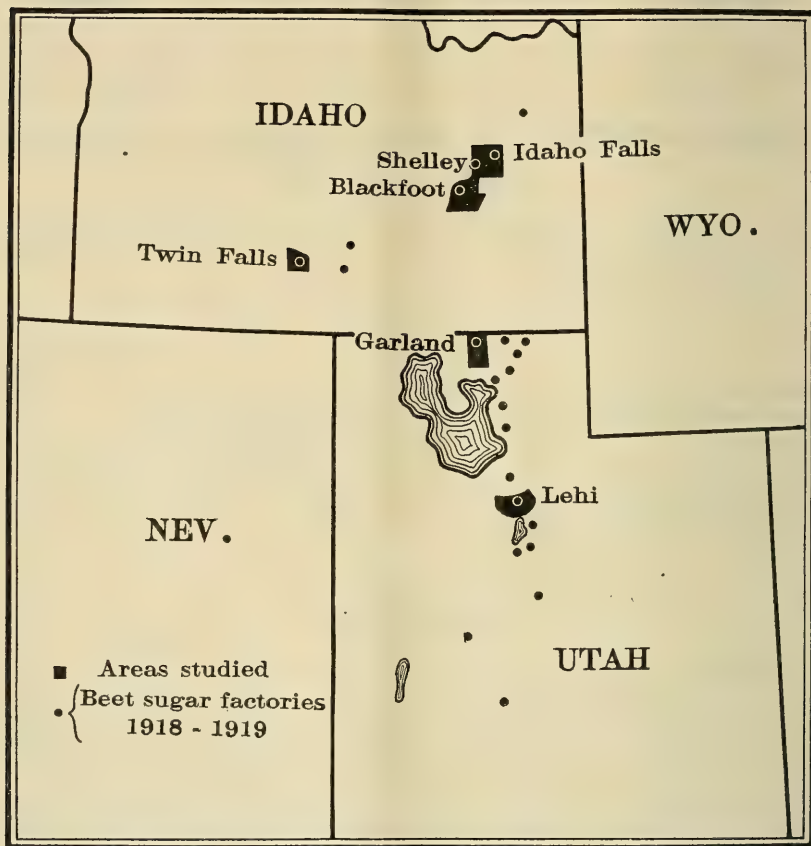


FIG. 1.—Location of areas surveyed.

enterprise, slightly more than 60 per cent of the total crop receipts coming from this source.

SCOPE AND METHOD OF STUDY.

This investigation, conducted primarily for the purpose of determining the individual farm costs involved in producing sugar beets during the years 1918 and 1919, is a continuation of work that was done in this field in 1915 and 1916. In planning and developing these studies the Office of Farm Management and Farm Economics

has worked in cooperation with the Office of Sugar-Plant Investigations, Bureau of Plant Industry.¹

In working out the cost figures in this bulletin, man labor was calculated by using an average rate per hour, based upon actual wages paid in 1918 and 1919. To place all records on the same basis, compensation for supervision of the farm business was omitted. The work of each operator was charged against the crop just as if some person had been hired to do each task. Likewise, the horse-labor cost was computed on the basis of the average price paid by farmers for this labor in the respective districts. If it is desired to bring the cost figures down to date, the hours of man labor and horse labor can be multiplied by prevailing rates. Similarly, changes can be made where increases or decreases have occurred in the cost of materials, supplies, rent of land, or other costs.

OBTAINING THE DATA.

The survey method was used. A special schedule was prepared and the blanks were filled out by well-trained enumerators, who visited the beet growers and obtained conservative estimates as to the methods and costs involved in growing the crop of the preceding year. Detailed records were obtained on the size of the crew and the normal time required in performing the various operations. Each grower was questioned systematically with reference to the successive steps that were taken in growing and harvesting the crop. Very few men keep systematic accounts of the daily work performed on each field or in connection with business transactions

¹ Some preliminary observations were made in these areas during the years 1910, 1911, and 1912. The work at that time dealt almost entirely with farm practice, although some attention was given to certain special problems of farm management. Cultural information was sought with a view to offering suggestions for a few districts where the beet growers were experiencing difficulty in producing satisfactory yields. Subsequently it was felt that data of this character would be of value in planning agronomic experiments which might have a direct bearing upon some of the more urgent problems of the beet grower. The field practice of one district has features which can be adapted with profit in another; and, if enough farms are studied, many general questions with reference to soil and crop management can be answered. The investigation was planned not only for the acquirement of field-practice information with reference to sugar beets, but it was also developed in such a way as to provide basic material concerning the hours of man labor and horse labor, the quantity of seed used, the pounds of fertilizer applied, tons of manure applied, and the utilization of land on farms where the sugar beet constituted one of the most important enterprises.

See the following bulletins: Department Bulletin No. 693, "Farm Practice in Growing Sugar Beets for Three Districts in Utah and Idaho;" Department Bulletin No. 726, "Farm Practice in Growing Sugar Beets for Three Districts in Colorado;" Department Bulletin No. 735, "Farm Practice in Growing Sugar Beets in the Billings Region of Montana;" Department Bulletin No. 748, "Farm Practice in Growing Sugar Beets in Michigan and Ohio;" Department Bulletin No. 760, "Farm Practice in Growing Sugar Beets in Three California Districts;" Farmers' Bulletin No. 1042, "Saving Man Labor in Sugar Beet Fields."

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which are made from time to time; but it has been found that an analysis of a suitable number of farm reports supplies material indicating clearly the trend of affairs in such a group, and that conclusions drawn therefrom can be regarded as significant.

PRESENTING THE DATA.

The first part of this bulletin includes a detailed analysis of the total cost of production. Here the total cost of man and horse labor, the total expense for materials, etc., are combined for the purpose of showing the average district cost of producing an acre or a ton of beets on the farms surveyed. These costs are distributed over the entire beet acreage for these farms. The practice sheets show the actual acreage covered, by operations, and the labor requirements are worked out for the number of acres covered by each implement. When the cost for operations not performed on all farms is charged against the entire beet crop the average is lowered. In determining a regional cost, the entire crop must bear any expense that may apply to a part of the acreage.

The second part describes in some detail the field operations which were employed in producing the 1918 and 1919 beet crops. Each district is treated as a unit and the tables show the percentage of total records and the percentage of total acreage covered in each operation. The most common crew is also given, and the average man and horse requirement for each of these field operations.

While the farm practice studies as a whole are applicable to 220 records, the different methods which are described were not followed on all farms. Plowing, harrowing with spike tooth, leveling, rolling-planting, cultivating, furrowing out and irrigating, blocking, thinning, hoeing, lifting, topping, loading, and hauling are operations common to most farms.

In presenting the farm practice data each district is discussed separately. The results have been compiled in such a way as to show the most common crew and the total average labor requirements for each of the four areas studied. The range in labor requirements is also given.

Tables are also given for the purpose of showing the range in unit cost for the individual farms included in this study. All farms are brought together in Table XIII. The respective districts are treated separately, with respect to range in cost per ton, in Tables XIV to XVII.

AREAS STUDIED.

Four distinct areas were included in this survey. In Utah County an area was selected in the vicinity of Lehi and 44 records were obtained. Utah County has been an important beet-producing center

for several years. The manufacture of sugar had its beginning in this State as early as 1852, but this pioneer venture did not prove successful. It remained for the farmers of Utah County to demonstrate at a later date the value of the sugar beet crop. The past 30 years have witnessed the development of an exceedingly important industry for farmers living within the Salt Lake basin and contiguous territory. The previous survey which was made in this county included some 58 enterprise survey reports that were obtained in the vicinity of Provo.

The Garland area is located in the Bear River Valley, in Boxelder County. Cost figures on sugar beets were secured in this district in



FIG. 2.—Beet sugar factory in the Bear River Valley, Utah, with a typical beet field in the foreground.

1915 and 1916. The present survey included 58 records, which were obtained in the vicinity of Tremonton and Garland. A beet-sugar factory was constructed at Garland in 1903. (Fig. 2.) In the year 1918 Boxelder County led all other counties in Utah in the number of acres planted to sugar beets.

The third district was selected in Bonneville and Bingham Counties in Idaho. Thirty-four reports were obtained from farmers near Idaho Falls and 40 from the vicinity of Blackfoot. These two sections are similar in many respects, and may be regarded as one district. A sugar factory was built at Idaho Falls in 1903. A factory

was also put up at Blackfoot about the same time. Thus the beginning of the industry in this area corresponds with the initial work in beet production at Garland, Utah.

In the Twin Falls area, 45 cost records were obtained. The area lies in the Snake River Valley and in many respects it is similar to the sections at Idaho Falls and Blackfoot. The beet industry is comparatively new in this section of the State. (For a discussion of the history of the sugar-beet industry in this region, and of climate and soil, see Department Bulletin 693.)

SIZE OF FARM.

The enterprise records for 1918-19 were confined almost entirely to farms producing 5 or more acres of beets. It was felt that the man who was growing less than 5 acres of beets would not be prepared to give detailed information on field operations.

All of the counties represented in this study contain a relatively large number of small farms, many planting not more than 3 or 4 acres to sugar beets. (See Table I.) A comparatively large number of farms in Utah County are under 9 acres; and more than one half of the farms are in the second group, 10 to 49 acres. The settlement of some of these districts dates back to 1846-1850, and as the practice at that time favored the smaller units it is not surprising to find a large number of such tracts at present. Boxelder County has a much larger land area than Utah County and a larger percentage of dry land, which has made necessary the development of many more farms of the larger sizes. The Idaho districts have been developed within more recent years, and although here also there is a tendency in the direction of the smaller units, farms containing a quarter section (160 acres) are much more common than in the Lehi district.

TABLE I.—*Farms grouped by size; all farms in area (1920 census) and farms studied.*

Size of farm.	Utah County.		Boxelder County.		Bingham County.		Bingham and Bonneville Counties.		Twin Falls County.	
	Number of farms in 1919.	Records obtained in 1918.	Number of farms in 1919.	Records obtained in 1918.	Number of farms in 1919.	Records obtained in 1918.	Number of farms in 1919.	Records obtained in 1918.	Number of farms in 1919.	Records obtained in 1919.
9 acres and under.....	428	-----	107	-----	103	-----	181	-----	1	-----
10 to 49 acres.....	1,674	24	520	29	876	28	817	13	817	13
50 to 99 acres.....	552	12	337	13	1,009	32	859	18	859	18
100 to 174 acres.....	280	7	268	12	775	9	588	11	588	11
175 to 259 acres.....	118	1	160	1	250	3	154	1	154	1
260 to 499 acres.....	100	-----	241	2	476	2	119	-----	119	-----
500 to 999 acres.....	51	-----	137	-----	112	-----	21	-----	21	-----
1,000 acres and over.....	34	-----	89	1	23	-----	7	-----	7	-----

¹ After the 1910 census, Bingham County was divided, and two counties were organized under the names Bingham and Bonneville.

TENURE OF FARMS SURVEYED.

A large percentage of the farms visited were operated by owners. The percentage of owned farms ranged from 74.3 per cent in the Lehi district to 86.8 per cent in the Garland area. (Table II). The second largest group includes tenant farmers who paid a cash rent. The smallest number was in the Garland district; and the largest number in the Lehi. Relatively few farmers rented on a share basis. There was considerable variation in the methods of share renting which were employed on these few farms. The three-quarter share appeared to be the most common.

TABLE II.—*Distribution of acreage by tenure.*

Region.	Total acres in beets.	Per cent of total beet acreage.						Cash rent.
		Owned.	One-half share.	Two-thirds share.	Three-fourths share.	Three-fifths share.	Four-fifths share.	
Lehi, Utah.....	303.50	74.3	-----	-----	0.7	-----	-----	25.0
Garland, Utah.....	766.00	86.8	2.2	-----	2.5	-----	-----	8.5
Idaho Falls and Blackfoot, Idaho.....	892.30	77.5	-----	1.4	2.0	-----	2.8	16.3
Twin Falls, Idaho.....	687.03	79.0	2.2	3.0	3.0	1.2	-----	11.6

DISTRIBUTION OF FARM AND CROP AREA.

There are at least three outstanding crops in these four districts—wheat, alfalfa, and sugar beets. A complete farm survey, including some 200 records from the Twin Falls area, indicates that field beans were somewhat more important than sugar beets during the year 1919. Sugar beets can be grown profitably in these areas only on that part of the farm which is supplied with irrigation water. Alfalfa is grown chiefly on irrigated land. The small grains are adapted to the dry-land farms.

In the initial survey made in Utah and Idaho the number of acres irrigated per farm was recorded, and from this the percentage of irrigated land devoted to sugar beets was determined. It was shown that approximately one-half the farm area in the Utah and Boxelder farms was irrigated and 35 to 42 per cent of the land under ditch was devoted to sugar beets. In the Idaho Falls area a much larger percentage of the farm land was classified as under the ditch and the proportion of this area devoted to sugar beets approximated 26 per cent. Estimates were not obtained in the present survey as to the area under irrigation. However, an analysis was made of the distribution of farm area and crop area. (Table III.)

In addition to the three important crops which have been mentioned, it should be noted that some attention is given to the potato in both of the Idaho areas. Oats are grown to some extent in the

Lehi district. A fairly large percentage of the crop acreage at Lehi and in the Garland section was under fallow. There was some fallow land on the irrigated farms. This was due to previous crop failure or to weed eradication. It may be assumed that the remainder of the crops grown on the fallow land were produced under dry farming conditions.

TABLE III.—*Distribution of farm and crop area.*

Items of comparison.	Utah.		Idaho.	
	Lehi.	Garland.	Idaho Falls and Blackfoot.	Twin Falls.
Number of records.....	44	58	74	44
Total acres per farm.....	59.33	92.98	79.29	75.33
Per cent of farm in tillable area.....	73.5	70.3	84.0	92.3
Per cent of farm in crops.....	69.9	69.2	78.0	84.6
Acres in crops.....	41.49	64.31	61.84	63.74
Percentage of crop acreage in—				
Alfalfa.....	21.7	21.1	33.9	21.9
Corn.....	.9	.5	.6	1.0
Sugar beets.....	17.1	20.7	21.2	24.5
Potatoes.....	2.3	.9	8.4	4.4
Hay.....	6.9	.3	.1	1.6
Wheat.....	30.9	29.8	26.8	27.0
Oats.....	7.1	3.9	4.6	2.0
Barley.....	2.6	1.6	.4	1.7
Fruit and garden.....	1.1	2.1	2.4	6.9
Fallow land.....	9.2	18.3	.2	.1
Beans.....	.1			5.9
Hay and alfalfa seed.....				2.8
Miscellaneous.....	.1	.8	1.4	.2

COMPARISON OF FARM ESTIMATES WITH FACTORY RECORDS.

Each sugar factory keeps a record of the acres planted to sugar beets and the tonnage harvested on each farm. These figures give not only the yield per acre for each farm, but also the average yield for the total acreage harvested. It is therefore possible to check a majority of the growers' estimates on acreage, yield, and receipts for this crop with the actual acreage, yield, and receipts as shown by the factory books. It has been the practice to discard estimates which obviously contained grave mistakes. In this way reliable figures are made available for comparison.¹

In the former study it was shown that the average estimated acreage per farm in the Garland district was 1.06 greater than the factory record. There was not much difference in the average yield as shown by the two methods in this district, and the cash returns were not far apart. The Utah county area indicated a very striking correspondence in the acreage and cash returns by the two methods, and the difference in yield per acre was insignificant. The Idaho Falls records included considerable variation in the yield per acre, and this was reflected in the income as reported for this crop.

¹ See Department Bulletin 529, "The Validity of the Survey Method of Research."

VALUE OF LABOR.

Each farmer furnished an estimate of the value of his own labor on the farm, of wages paid out for regular and extra labor, and of the value of horse labor. (Table IV.)

TABLE IV.—*Current rates per hour for labor.*

	Lehi (1918).	Garland (1918).	Idaho Falls and Blackfoot (1918).	Twin Falls (1919).
Man-labor rate.....	\$0.40	\$0.45	\$0.40	\$0.45
Horse-labor rate.....	.15	.15	.15	.15

There was only a slight difference in the average rate per hour for labor in these four districts. The customary rate for man labor appeared to be 40 to 45 cents per hour, which would mean \$4 to \$4.50 per 10-hour day. The uniform charge for horse labor was 15 cents per hour, or \$3 per day per span of horses. The seasonal variation during the years 1918 and 1919 was small. If studies had been made in the Lehi, Idaho Falls, and Blackfoot areas for the year 1919, the man-labor rate probably would have been somewhat higher, and possibly the horse-labor rate.

The value of both man labor and horse labor has increased perceptibly within the past three or four years. In view of the fact that money values have changed appreciably during that time greater attention should be given to those requirements which show comparatively small variation from year to year.

Since the labor requirements of any crop, except as they are modified by the introduction of new methods, change but little from season to season, if the time required in producing a given crop is recorded in hours the labor cost at any specified time can be determined by applying the rate for that particular period.

In presenting these data, basic requirements, such as hours of man labor, hours of horse labor, tons of manure applied, quantity of seed used, and the systems of tenure under which the land was operated, have been given special emphasis.

COST OF PRODUCING SUGAR BEETS.

The cost figures have been assembled under three headings—labor, materials, and other costs. The compilation includes the total number of acres harvested. These data are therefore applicable to the total beet acreage reported in 44 Lehi, 58 Garland, 74 Idaho Falls, and 44 Twin Falls records. In the Lehi area 303.5 acres of sugar beets were covered. At Garland the harvested acreage amounted to 766, at Idaho Falls 892.3 acres, and at Twin Falls 687 acres. The total cost for each district was based upon these acreages. Dividing

the total of all costs in each district by the number of acres grown therein gave the cost per acre for each section. The cost of production of a ton of sugar beets in the respective areas was determined by dividing the total of all costs by the total number of tons marketed. A weighted average is therefore represented in the final result.

LABOR COSTS.

Labor is made up of operators' labor, horse labor, and contract hand labor. By adding these together the total labor cost for each district was determined (Table V.)

TABLE V.—*Labor costs.*

Region.	Year.	Number of farms.	Total acres harvested.	Labor costs per acre.						Range in labor costs.			
				Man labor.	Contract hand labor.	Other contract labor.	Horse labor.	Total cost per acre.	Cost per ton.	Per acre.		Per ton.	
										Average of highest 5.	Average of lowest 5.	Average of highest 5.	Average of lowest 5.
Utah:													
Lehi.....	1918	44	303.5	\$61.88	\$8.02	\$1.98	\$23.65	\$95.53	\$5.93	\$128.75	\$67.57	\$9.65	\$3.92
Garland.....	1918	58	766	38.82	20.92	3.71	17.95	81.40	5.14	110.45	61.24	8.20	3.65
Idaho:													
Idaho Falls and Blackfoot.....	1918	74	892.3	30.63	18.12	2.42	14.42	65.59	5.01	100.99	47.73	10.26	3.30
Twin Falls.....	1919	44	687.03	28.28	27.06	3.78	14.86	73.98	6.78	120.03	55.17	14.60	4.50

COST OF MATERIALS.

Cost of materials includes the value of manure in the yard, money spent for the purchase of manure on a few farms, expense for beet seed, and water assessments. (Table VI.)

TABLE VI.—*Cost of materials.*

District.	Year.	Number of farms.	Total acres harvested.	Cost per acre.				Cost per ton.
				Manure.	Seed.	Water.	Total.	
Lehi, Utah.....	1918	44	303.5	\$9.82	\$2.07	\$2.09	\$13.98	\$0.87
Garland, Utah ¹	1918	58	766	5.05	1.96	.92	7.93	.50
Idaho Falls and Blackfoot, Idaho.....	1918	74	892.3	6.07	1.84	1.10	9.01	.69
Twin Falls, Idaho.....	1919	44	687.03	3.46	2.29	3.15	8.90	.82

¹ The usual charge for water in the Garland district was \$1 per acre. The average cost shown in this table is slightly less than this amount, and it signifies that a few of the operators were renters and the assessments for water were paid by the landlord.

There was considerable difference in the rate of application of manure for the respective districts. The maximum application occurred in the Lehi district. This feature is explained more fully in a discussion concerning the practice of manuring in these areas. The fact that Lehi growers made a very heavy application accounts in a large part for the comparatively high manure charge which is shown in Table VI.

SEED.

The common practice was to plant beet seed at the rate of 15 pounds per acre. The seed was sold to the grower at approximately 15 cents per pound, thus making a uniform rate of \$2.25 per acre. Several farmers used less than 15 pounds per acre, and as a result three districts have an acre charge for seed which is somewhat less than \$2.25.

WATER ASSESSMENTS.

The farms in the Garland area reported an assessment of approximately \$1 per acre for irrigation water. This group, however, contained some rented farms. In such cases the water assessments were not paid by the operator, but were included with the rent. When these farms are included the average cost is lower than \$1 per acre.

OTHER COSTS.

"Other costs" are charges which apply to the farm as a whole. They must, therefore, be distributed so that each enterprise will carry its proper proportion of the general expenses. Such items as insurance, taxes, interest on land, land rent, machinery charges, and miscellaneous expense constitute this list. (Table VII.)

TABLE VII.—*Other costs—use of land, taxes, overhead, etc.*

District.	Year.	Number of farms.	Total acres harvested.	Cost per acre.							Cost per ton.	
				Use of land.	Taxes and insurance.	Interest on borrowed money.	Machinery.	Roller hire.	Loss due to abandoned acreage.	Overhead.		Total.
Lehi, Utah.....	1918	44	303.5	\$18.82	\$1.92	-----	\$9.24	\$0.20	\$0.95	\$10.95	\$42.08	\$2.61
Garland, Utah..	1918	58	766	22.77	1.36	\$0.04	8.52	.16	.29	8.93	42.07	2.66
Idaho Falls and Blackfoot, Idaho.....	1918	74	892.3	19.99	1.29	-----	8.74	.09	3.24	7.46	40.81	3.12
Twin Falls, Idaho.....	1919	44	687.03	34.29	3.70	-----	7.19	.04	-----	8.29	53.51	4.90

^a In these areas 7.8 per cent of the sugar beet acreage was abandoned.

USE OF LAND.

Every farm owner has a given amount of capital invested in land and a reasonable return is expected annually. In some methods of accounting it is customary to omit the "rent" charge, but in this study allowance is in all cases made for use of land. A large number of farmers in these areas have mortgages on their farms, and they pay a definite rate of interest annually. Clearly this interest is chargeable against the crop grown upon the land. Similarly, interest on investment should be charged against crops grown on land not

mortgaged. Since on the farms studied the beet land was given a higher land valuation, sugar beets assumed a greater proportion of the interest cost than the remaining crop enterprises.

Land rent is directly related to interest charges; but it should be borne in mind that the share or cash payment for the rent of land not only covers interest on investment in such land, but also takes care of land taxes, insurance, and assessments for irrigation water.

On farms where the greater part of hand labor is on a contract basis it is the custom for the sugar company to advance the operator sufficient money to pay approximately one-half of the total cost of hand labor as soon as the thinning and hoeing have been completed. The amount of this loan, with interest, is deducted from the beet receipts in the autumn. This interest is a part of the cost of raising beets, and it has been so charged in this study.

INSURANCE AND TAXES.

Figures on farm insurance, taxes, total real-estate investment, and value of the land per acre, were obtained from each operator. From these data the investment in beet land was computed and from this the percentage of the beet-land investment to the total real-estate investment was determined. By applying this percentage to the total farm insurance and taxes the charge against sugar beets was ascertained. This method was employed where the operator owned the land. Where the operator was a renter the insurance and taxes were usually negligible.

MACHINERY.

The annual cost of machinery includes such expenses as repairs, fuels, lubricants, labor of upkeep, depreciation, interest, and insurance, minus credits for machinery hired out. A part of the equipment used in the preparation of beet land is required in caring for other crops, hence the annual machinery charge must be distributed as equitably as possible over the enterprises involved. An arbitrary plan was employed in assigning the machinery charge to the crop enterprises, but in doing this an attempt was made to give each crop its proper weight so that the expense would be distributed proportionately. The machinery charge was fairly uniform throughout all districts. A separate charge of a few cents per acre is included for the hire of rollers by some operators in all of these districts.

OVERHEAD.

There are certain other costs which are not chargeable to any one enterprise in particular, but have to be carried by the farm as a whole, as overhead, a certain share by each enterprise. To make

provision for these items a 10 per cent charge was taken on the basis of labor and material costs combined.

SUMMARY OF ALL COSTS.

The distribution of costs has been determined with the charge for land included, and also without a charge for land. These figures are given in Tables VIII and IX.

TABLE VIII.—*Summary and distribution of average costs (including use of land).*

District.	Year.	Cost per acre.	Cost per ton.	Percentage distribution of costs.		
				Labor.	Materials.	Other costs.
Lehi, Utah.....	1918	\$151.59	\$9.41	63.0	9.2	27.8
Garland, Utah.....	1918	131.40	8.29	62.0	6.0	32.0
Idaho Falls and Blackfoot, Idaho.....	1918	115.41	8.82	56.8	7.8	35.4
Twin Falls, Idaho.....	1919	136.39	12.50	54.2	6.5	39.3

By comparing Tables VIII and IX it will be seen that at least one significant change is made in the percentage distribution of costs when the charge for the use of land is excluded. The percentage of total cost for labor becomes much more uniform. In fact, the exclusion of interest on land, or land rent, brings the percentage distribution of costs for the three groups on a uniform basis for practically all districts.

TABLE IX.—*Summary and distribution of average costs (excluding use of land).*

District.	Year.	Cost per acre.	Cost per ton.	Percentage distribution of costs.		
				Labor.	Materials.	Other costs.
Lehi, Utah.....	1918	\$132.77	\$8.24	72.0	10.5	17.5
Garland, Utah.....	1918	108.63	6.85	74.9	7.3	17.8
Idaho Falls and Blackfoot, Idaho.....	1918	95.42	7.29	68.7	9.5	21.8
Twin Falls, Idaho.....	1919	102.10	9.36	72.5	8.7	18.8

Not counting the use of land, labor constitutes approximately 70 to 75 per cent of the total cost of producing sugar beets in this area. When interest (or rent) is included, the total labor costs vary from 54 to 63 per cent of the total cost.

AVERAGE RETURNS AND MARGIN ABOVE COST.

The highest average yield per acre was reported by the 44 Lehi farms, 16.1 tons for the year 1918. The minimum average yield was reported from the Twin Falls area. However, the Twin Falls area should not be compared directly with the other three regions

for the reason that the records for the Twin Falls farms pertain to the crop season 1919. (Table X.)

TABLE X.—Average returns and margin above cost.

Region.	Number of farms.	Acres in beets.	Yield per acre.	Received per acre.	Cost per acre.	Net returns per acre.	Total net returns per acre, including tops.	Credit and sales from beet tops.
			<i>Tons.</i>					
Lehi, Utah.....	44	303.5	16.1	\$161.77	\$151.59	\$10.18	\$16.49	\$6.31
Garland and Tremonton, Utah..	53	766	15.8	158.41	131.40	27.01	31.33	4.32
Idaho Falls and Blackfoot, Idaho	74	892.3	13.1	130.80	115.41	15.39	20.03	4.64
Twin Falls, Idaho.....	44	687.03	10.9	119.87	136.39	-16.52	-11.51	5.01

It will be seen that net returns from beets varied from \$27 per acre as a profit in the Garland area to a loss of \$16.52 in the Twin Falls area. By adding the value of tops in each district the margins are increased somewhat for the first three districts and the loss is reduced somewhat for the Twin Falls district. It should be borne in mind that the Twin Falls growers did not sustain an actual cash loss as indicated in the above table, since in addition to interest on investment the crop was charged 45 cents per hour for all labor expended on sugar beets by the operators. Possibly these men would be willing to accept a slightly lower rate than the amount that was used in computing these costs.

PERCENTAGE RETURN ON INVESTMENT AS INFLUENCED BY LAND VALUES.

The results which were obtained on these farms during the years 1918-1919 may be expressed in the form of interest accruing from money invested in the sugar beet business. To say that all farms earned a definite percentage on investment would not be correct, because certain individuals realized a much higher rate, while others fell considerably below this percentage. Furthermore, there was quite a wide range in land values as estimated by these growers. In the Lehi area the lowest estimated land value was \$100 per acre, while the highest was \$400 per acre; at Garland the range was \$150 to \$350; in the Idaho Falls district \$100 to \$350; and in the Twin Falls district, \$350 to \$800.

What interest did these men earn on the capital invested in the sugar-beet business? This question is answered in part in Table XI, showing cost per acre and percentage return on investment on the basis of different land values.

During the war period the prices of farm products increased and land values went up. However, there was a tendency for the prices of land to lag behind the prices of farm products. So long as farm products commanded good prices, it was possible under average conditions to have sufficient margin after paying for labor and meeting

other farm expenses to pay the going interest rate on the land investment. It will be admitted that the values which obtained under war conditions were in part speculative values. In a period of declining prices for farm products, adjustments have to be made in the farm business. One adjustment that should receive early consideration has to do with land valuation. Success in the arrangement of the farm will depend in part upon the earnings that accrue and are available to pay for capital. If the land is overvalued, the rate may be exceedingly low.

TABLE XI.—*Cost of sugar beets per acre (excluding use of land) and percentage return on investment as influenced by land values.*

Region.	Year.	Number of farms.	Yield per acre.	Total cost per acre.	Return per acre. ¹	Margin per acre.	Percentage return on investment with land at—					Average land value as reported.
							\$200	\$300	\$400	\$500	\$600	
Utah:			<i>Tons.</i>									
Lehi.....	1918	44	16.1	\$132.77	\$168.08	\$35.31	17.7	11.8	8.8	7.1	5.9	\$215
Garland.....	1918	58	15.8	108.63	162.73	54.10	27.0	18.0	13.5	10.8	9.0	259
Idaho:												
Idaho Falls and												
Blackfoot.....	1918	74	13.1	95.42	135.44	40.02	20.0	13.3	10.0	8.0	6.7	228
Twin Falls.....	1919	44	10.9	102.10	124.88	22.78	11.4	7.6	5.7	4.6	3.8	442

¹ Including beets and beet tops.

If the different values as given by these farmers are applied, it will be seen that there was quite a wide range in the returns on investment. Relatively good yields were reported in the three districts surveyed in 1918, while in the fourth district, surveyed in 1919, the crop was rather poor. This fact should not be overlooked in making a comparison of results. With the unfavorable conditions that obtained at Twin Falls and the comparatively high land values shown in these estimates, it was not possible to earn a high interest rate.

A study of results through a series of years in all of these districts would doubtless be of great value. From the standpoint of farm organization it is highly desirable to compare one enterprise with another, using the interest earned on investment as a basis for judging results.

VALUE OF TOPS.

More attention is being given from year to year to the utilization of beet tops. The high price of hay in the intermountain region within the past two years has compelled farmers in this area to conserve the supplies of roughage on the farm. Beet tops have therefore been saved and have been fed more carefully within recent years than formerly. Certain methods of handling beet tops entail considerable waste under present systems of management. On some of these farms the beet tops were sold to men who had cattle

or sheep to feed. This provided a cash return to the farmer and was considered in the present analysis. (Table X.)

BEEF ACREAGE PER FARM AND PER ACRE IN RELATION TO COST.

As has already been pointed out, yield per acre is an important factor when making a study of crop costs. The number of acres planted per farm also appears to exert influence on cost of production. (Table XII.)

Increasing the yield per acre made the total cost per acre greater, but each successive increase in yield reduced the cost per ton. It would seem that the grower who is producing from 15 to 18 tons per acre, either in small, medium, or comparatively large tracts, can grow and market these beets at a much lower cost per ton than the man who gets 12 tons or less per acre under similar conditions. With greater efficiency in handling a few of the major operations, higher yields would undoubtedly result, and this in turn would appreciably increase the margin above cost. In Table XII there are at least two groups too small to be safely used as a basis for conclusions, but the general trend of the farm in the respective groups indicates that yield per acre is an important factor and that the farms with the larger acreages in sugar beets produced the crop more economically than the smaller farms.

TABLE XII.—*Acres in beets and yield per acre as influencing cost of production.*

Acres in sugar beets.	Yield 12 tons or less per acre.			Yield 12 to 15 tons.			Yield 15 to 18 tons.			Yield over 18 tons.		
	Number of farms.	Cost per acre.	Cost per ton.	Number of farms.	Cost per acre.	Cost per ton.	Number of farms.	Cost per acre.	Cost per ton.	Number of farms.	Cost per acre.	Cost per ton.
Under 10.....	42	\$124.24	\$13.99	27	\$147.45	\$10.45	28	\$142.73	\$8.59	24	\$162.81	\$7.45
10 to 15.....	24	110.11	12.29	11	134.95	9.45	15	132.13	8.01	7	136.54	6.73
15 and over.....	13	121.95	13.69	14	122.63	8.65	14	132.42	7.98	1	127.55	6.54

RANGE IN COST PER TON.

The accompanying frequency chart (fig. 3) shows the distribution of farm operators in these four districts on the basis of cost per ton in producing sugar beets. In this study the records for the two crop years 1918-19 have been combined. There were two growers in these areas who produced sugar beets at a cost of \$5 per ton. These men obtained an average yield of 24 tons per acre. The maximum unit cost for an individual farm was \$35 per ton, incurred by an operator who had a yield of but 3 tons per acre. Another individual had a cost of \$34 per ton. Here the yield was approximately 7 tons per acre harvested, but a part of the planted acreage was abandoned.

Comparatively low yields explain many of the other high costs which are shown in the frequency tables. (Tables XIII to XVII.)

Seventy-two per cent of these growers produced sugar beets at a cost of \$11 per ton or less. The cost groups \$5 to \$11, inclusive, had 75.9 per cent of the harvested acreage and 85 per cent of the total

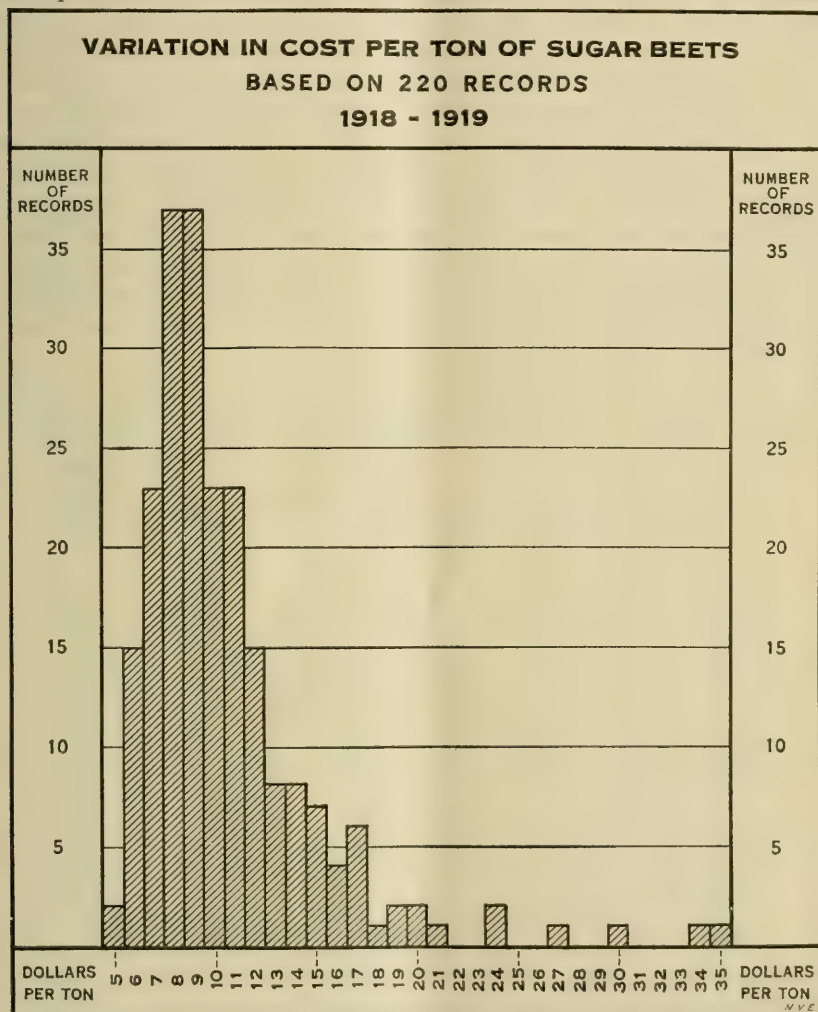


FIG. 3.—Frequency chart, showing range in cost per ton.

production of the farms represented in this study. The average yield for the 23 farms producing at a cost of \$11 per ton was 12.3 tons per acre. Essentially 80 per cent of the operators, 81 per cent of the harvested acreage, and 89 per cent of the total production are covered by a cost of \$12 per ton or less.

IMPORTANCE OF YIELD.

On practically every farm there are opportunities to place the field work upon a more efficient basis. Every operator is willing to concede that some slight change in present methods would undoubtedly be a step in the direction of greater crop yields. It has been pointed out that the sugar beet is not always grown in the regular cropping system. Continuous culture may therefore be preventing the grower from getting maximum results. In other cases a lack of fertility may be the limiting factor, although in all four districts nearly every grower gave considerable attention to the application of farm manure. Inadequate preparation of soil or careless seeding may give a poor stand, which makes a good yield impossible, or the blocking and thinning may be done in such a way as to interfere seriously with the stand. These are factors which should be kept in mind throughout the season, and if weak places are found in the present methods of operation and management they should be corrected as far as possible.

TABLE XIII.—*Variation in cost per ton—summary, Utah and Idaho sugar beet districts, 1918 and 1919 (220 records).*

Cost per ton.	Number of records.	Cumulative percentage of records.	Acres.		Cumulative percentage of harvested acreage.	Production.	Cumulative production.	Cumulative percentage of production.
			Seeded.	Harvested.				
\$5.00	2	0.9	15	15	0.6	<i>Tons.</i> 365	<i>Tons.</i> 365	1.0
6.00	15	7.7	171.3	171.3	7.1	3,328.5	3,693.50	10.2
7.00	23	18.1	291.5	287.5	17.9	4,790.78	8,484.28	23.4
8.00	37	34.9	486.5	478.5	36.0	7,831.3	16,315.58	45.0
9.00	37	51.7	536	536	56.2	7,861.8	24,177.38	66.7
10.00	23	62.1	290.75	275.25	66.6	3,619.3	27,796.68	76.7
11.00	23	72.6	253	247	75.9	3,026	30,822.68	85.1
12.00	15	79.4	134.2	134.2	81.0	1,410.9	32,233.58	89.0
13.00	8	83.0	85.33	79.33	84.0	746.7	32,980.28	91.1
14.00	8	86.6	69	69	86.6	592.2	33,572.48	92.7
15.00	7	89.8	59.5	58.5	88.8	488.3	34,060.78	94.1
16.00	4	91.6	38.25	35.25	90.1	293	34,353.78	94.9
17.00	6	94.3	91	63.5	92.5	566.75	34,920.53	96.5
18.00	1	94.8	5	5	92.7	71.75	34,992.28	96.7
19.00	2	95.7	52.75	52.75	94.7	300.7	35,292.98	97.5
20.00	2	96.6	17	13	95.2	77	35,369.98	97.7
21.00	1	97.1	85	85	98.4	595	35,964.98	99.3
22.00								
23.00								
24.00	2	98.0	13.75	13.75	98.9	78	36,042.98	99.5
25.00								
26.00								
27.00	1	98.5	15	15	99.5	67.5	36,110.48	99.7
28.00								
29.00								
30.00	1	99.0	5	5	99.7	30	36,140.48	99.8
31.00								
32.00								
33.00								
34.00	1	99.5	20	5	99.9	35	36,175.48	99.9
35.00	1	100.0	4	4	100.0	12	36,187.48	100.0

Average cost per ton, \$9.49.

Average yield per acre, 13.7 tons.

RANGE IN ACRE COSTS.

The accompanying range tables are devoted exclusively to variations in unit cost per ton. It is of interest also to compare the individuals which are included in this study from the standpoint of acre costs. These figures are given in Table XVIII.

TABLE XIV.—*Variation in cost per ton—Lehi, Utah (1918).*

Cost per ton.	Number of records.	Cumulative percent. of records.	Acres.		Cumulative percentage of harvested area.	Production.	Cumulative production.	Cumulative percentage of production.
			Seeded.	Harvested.				
\$5.00	1	2.3	5	5	1.6	Tons. 135	Tons. 135	2.8
6.00	1	4.6	6	6	3.6	130	265	5.5
7.00	4	13.7	29	29	13.2	615	880	18.0
8.00	7	29.6	48.5	48.5	29.1	942.1	1,822.1	37.4
9.00	7	45.5	51.5	51.5	46.1	902	2,724.1	55.8
10.00	9	65.9	81	77	71.6	1,051	3,775.1	77.4
11.00	6	79.5	28	28	80.9	432	4,207.1	86.1
12.00	4	88.6	30	30	90.7	364	4,571.1	93.5
13.00	1	90.9	4	4	92.0	60	4,631.1	94.7
14.00	1	93.2	9	9	95.0	117	4,748.1	97.1
15.00	2	97.7	12.5	11.5	98.7	108.5	4,856.6	99.3
16.00	-----	97.7	-----	-----	98.7	-----	-----	99.3
17.00	-----	97.7	-----	-----	98.7	-----	-----	99.3
18.00	-----	97.7	-----	-----	98.7	-----	-----	99.3
19.00	-----	97.7	-----	-----	98.7	-----	-----	99.3
20.00	1	100.0	8	4	100.0	32	4,888.6	100.0

Average cost per ton, \$9.41.

Average yield per acre, 16.1 tons.

NOTE.—Approximately 80 per cent of the operators in this district produced sugar beets at a cost of \$11 per ton or less. The unit costs for the groups, \$5 to \$11, inclusive, embraced 81 per cent of the harvested acreage and 86 per cent of the total production. The farm having the lowest unit cost in this district secured a yield of 27 tons per acre, whereas the farm reporting the highest unit cost at a yield of 8 tons per acre. It should also be noted that in the latter case only 50 per cent of the seeded acreage was harvested.

TABLE XV.—*Variation in cost per ton—Garland, Utah (1918).*

Cost per ton.	Number of records.	Cumulative percent. of records.	Acres.		Cumulative percentage of harvested acreage.	Production.	Cumulative production.	Cumulative percentage of production.
			Seeded.	Harvested.				
\$5.00	1	1.7	10	10	1.3	Tons. 230	Tons. 230	1.9
6.00	7	13.8	49.5	49.5	7.8	1,031.7	1,261.7	10.4
7.00	9	29.4	109	109	22.0	1,915.5	3,177.2	26.2
8.00	18	60.4	303	299	60.9	4,866.5	8,043.7	66.4
9.00	10	77.6	159	159	81.7	2,309.5	10,353.2	85.4
10.00	4	84.5	37	37	86.6	598	10,951.2	90.3
11.00	7	96.6	88.5	86.5	97.9	1,070	12,021.2	99.1
12.00	-----	96.6	-----	-----	97.9	-----	-----	99.1
13.00	-----	96.6	-----	-----	97.9	-----	-----	99.1
14.00	1	98.3	9	9	99.1	64	12,085.2	99.6
15.00	-----	98.3	-----	-----	99.1	-----	-----	99.6
16.00	-----	98.3	-----	-----	99.1	-----	-----	99.6
17.00	1	100.0	7	7	100.0	49	12,134.2	100.0

Average cost per ton, \$8.29.

Average yield per acre, 15.8 tons.

NOTE.—The lowest unit cost in this area was \$5 per ton, and the operator who obtained this result had a yield of 23 tons per acre. The highest unit cost was \$17 per ton on a farm having a yield of 7 tons per acre. The groups in this district which had costs ranging from \$5 to \$9 per ton included approximately 78 per cent of the operators, 82 per cent of the harvested acreage, and 85 per cent of the total production.

The lowest cost per acre was \$75.48 and the highest was \$253.66. The largest single group, having 81 farms, reported acre costs of from \$125 to \$150, while the second largest group, with 70 farms, had acre costs of from \$100 to \$125. These two groups taken together constitute approximately 69 per cent of the total number of farms visited,

TABLE XVI.—*Variation in cost per ton—Idaho Falls and Blackfoot (1918).*

Cost per ton.	Number of records.	Cumulative percentage of records.	Acres.		Cumulative percentage of harvested acreage.	Production.	Cumulative production.	Cumulative percentage of production.
			Seeded.	Harvested.				
\$6.00	7	9.5	115.8	115.8	13.0	<i>Tons.</i> 2,166.80	<i>Tons.</i> 2,166.80	18.6
7.00	10	23.0	153.5	149.5	29.8	2,260.28	4,427.08	38.0
8.00	12	39.2	135	131	44.5	2,022.70	6,449.78	55.3
9.00	12	55.4	145	145	60.8	1,906.50	8,356.28	71.7
10.00	8	66.2	130.5	119	74.1	1,290.80	9,647.08	82.8
11.00	7	75.7	80.5	76.5	82.7	808	10,455.08	89.7
12.00	3	79.8	25	25	85.5	254.50	10,709.58	91.9
13.00	3	83.9	31	25	88.3	236	10,945.58	93.9
14.00	2	86.6	20	20	90.5	154.20	11,099.78	95.2
15.00	3	90.7	26	26	93.4	178	11,277.78	96.7
16.00	1	92.0	12	9	94.4	63	11,340.78	97.2
17.00	3	96.1	51	23.5	97.0	187.75	11,528.53	98.8
18.00								
19.00	1	97.4	13	13	98.4	63	11,591.53	99.3
20.00	1	98.7	9	9	99.4	45	11,636.53	99.7
34.00	1	100.0	20	5	100.0	35	11,671.53	100.0

Average cost per ton, \$8.82.

Average yield per acre, 13.1 tons.

NOTE.—There was a wide variation in the unit costs reported for the 74 farms in this district. The minimum cost per ton was \$6, while the maximum was \$34. The seven farms with the minimum unit cost produced an average yield of 18.7 tons per acre. The farm operator with the high unit cost had a yield of 7 tons per acre. The unit cost on the latter farm was accentuated owing to the abandonment of three-fourths of the planted acreage. The groups with unit costs ranging from \$6 to \$11, inclusive, embraced 76 per cent of these growers, 83 per cent of the harvested acreage, and 90 per cent of the total production.

TABLE XVII.—*Variation in cost per ton—Twin Falls, Idaho (1919).*

Cost per ton.	Number of records.	Cumulative percentage of records.	Acres.		Cumulative percentage of harvested acreage.	Production.	Cumulative production.	Cumulative percentage of production.
			Seeded.	Harvested.				
\$9.00	8	18.2	180.50	180.50	26.3	<i>Tons.</i> 2,743.8	<i>Tons.</i> 2,743.8	36.6
10.00	2	22.7	42.25	42.25	32.4	679.5	3,423.3	45.7
11.00	3	29.5	56	56	40.6	716	4,139.3	55.3
12.00	8	47.7	79.20	79.20	52.1	792.4	4,931.7	65.9
13.00	4	56.8	50.33	50.33	59.4	450.7	5,382.4	71.9
14.00	4	65.9	31	31	63.9	257	5,639.4	75.3
15.00	2	70.4	21	21	67.0	201.8	5,841.2	78.0
16.00	3	77.2	26.25	26.25	70.8	230	6,071.2	81.1
17.00	2	81.7	33	33	75.6	330	6,401.2	85.5
18.00	1	84.0	5	5	76.3	71.75	6,472.95	86.5
19.00	1	86.3	39.75	39.75	82.1	237.7	6,710.65	89.7
20.00								
21.00	1	88.6	85	85	94.5	595	7,305.65	97.6
22.00								
23.00					96.5	78	7,383.65	98.6
24.00	2	93.1	13.75	13.75				
25.00								
26.00								
27.00	1	95.4	15	15	98.7	67.5	7,451.15	99.5
28.00								
29.00								
30.00	1	97.7	5	5	99.4	30	7,481.15	99.9
31.00								
32.00								
33.00								
34.00								
35.00	1	100.0	4	4	100.0	12	7,493.15	100.0

Average cost per ton, \$12.50.

Average yield per acre, 10.9 tons.

NOTE.—Attention has been directed to the fact that average farm operators in this group lost money on the 1919 crop of beets. It should be remembered that these men were allowed 45 cents per hour for their labor and the current rate of interest for the money invested in their business. The minimum unit cost was \$9 per ton and the maximum \$35 per ton. The average yield for the eight low cost farms was 15.2 tons per acre, whereas the farm having the highest unit cost produced only 3 tons per acre. There were six farms on which the unit costs exceeded \$20 per ton. The yields on these farms ranged from 3 to 7 tons per acre.

and indicate a range in acre costs from \$100 to \$150. It will be noted that as the cost per acre increases the yield per acre also advances. Between the 18 farms in group one and the 21 farms in group five there is a difference of 8.2 tons per acre. Apparently the point of diminishing returns was not reached on these farms.

TABLE XVIII.—*Variation in the cost per acre—all districts (1918-1919).*

Cost per acre.	Number of farms.	Cumulative percentage of number of farms.	Acres.		Cumulative percentage of harvested acreage.	Yield.	Cumulative yield.	Cumulative percentage of yield.	Yield per acre.
			Seeded.	Harvested.					
						<i>Tons.</i>	<i>Tons.</i>		<i>Tons.</i>
\$100 and under.....	18	8.2	213.5	213.5	8.1	2,036.6	2,036.6	5.6	9.5
\$100 to \$125.....	70	40.0	1,011.05	991.05	45.5	12,252.3	14,288.9	39.5	12.4
\$125 to \$150.....	81	76.8	1,076.33	1,031.53	84.4	15,120.83	29,409.73	81.3	14.7
\$150 to \$175.....	30	90.4	290.25	280.25	95.0	4,427.50	33,837.23	93.5	15.8
Over \$175.....	21	100.0	147.50	132.50	100.0	2,350.25	36,187.48	100.0	17.7

CROP ROTATION.

Within recent years the question of introducing systematic cropping on the farms of this general region has been given some attention. While it is true that there are some farms in each area where individual crops are grown continuously upon the same land, the value of a good rotation is conceded by progressive farmers. However, it is apparent that good working systems have been adopted on relatively few farms. Some farmers are limited by the number of crops which may be grown under their individual conditions. Some farms contain dry land as well as irrigated land. The dry land is of necessity devoted to the production of grain exclusively, whereas the irrigated land is set aside for alfalfa, sugar beets, and truck, fruit, or garden crops. It will be seen that this arrangement makes it impossible for some of these men to use grain at regular intervals in rotation with sugar beets. Each crop has its adaptations, and these characteristics must be taken into account in laying out a cropping system. With this situation facing the grower, there is a natural tendency to allow sugar beets to follow sugar beets on the same field for several years. The location of the field with reference to beet dumps and roads often has much to do with its selection for sugar beets.

The survey schedule contained two questions which were used for the purpose of determining the crop or crops which preceded sugar beets; also the crop or crops which were or would be planted after sugar beets. A summary of this analysis is given in Table XIX.

In the Lehi district nearly 60 per cent of the best acreage represented on the farms included in this survey was planted on land

which had produced a crop of beets the preceding year. Sugar beets followed the 1918 crop on essentially 56 per cent of the Lehi acreage upon which these cost figures are based. About one-third of the beet crop was grown after grain in both the Lehi and Twin Falls districts. The Garland and Idaho Falls growers reported that sugar beets followed beets on 84 per cent and 71 per cent, respectively, during the year 1918. Continuous culture was employed to a somewhat greater extent in 1919.

TABLE XIX.—*Occurrence of sugar beets in cropping system.*

PERCENTAGE OF TOTAL SUGAR BEET ACRES FOLLOWING CROPS SPECIFIED.

Region.	Beets.	Pota- toes.	Alfalfa.	Pas- ture.	Grain.	Miscel- laneous.	Total.
Lehi, Utah.....	57.2	10.7	0.4	.....	28.6	3.1	100.0
Garland and Tremonton, Utah.....	83.8	.8	8.1	.....	7.3	.....	100.0
Idaho Falls and Blackfoot, Idaho.....	71.3	22.5	2.3	0.7	2.8	.4	100.0
Twin Falls, Idaho.....	31.2	9.8	22.0	.....	33.6	3.4	100.0

PERCENTAGE OF TOTAL SUGAR BEET ACRES FOLLOWED BY CROPS SPECIFIED.

Lehi, Utah.....	55.9	1.1	.....	.....	43.0	.....	100.0
Garland and Tremonton, Utah.....	96.1	.....	1.1	.....	2.8	.....	100.0
Idaho Falls and Blackfoot, Idaho.....	78.6	8.9	.....	.....	12.5	.....	100.0
Twin Falls, Idaho.....	52.2	.....	.....	.....	47.8	.....	100.0

Both the enterprise survey which was carried out in these districts in 1915 and 1916 and the present survey appear to indicate that quite a large number of growers favor the production of sugar beets on the same piece of land for several years in succession. This practice is no doubt due in part to the prevailing opinion that beet land improves with cultivation. Many growers contend that they are getting better yields now in fields that have produced five or more crops than they were able to obtain during the first two or three years of their experience. It is not unusual to find beets upon the same field for eight to twelve years without the introduction of any other crop. Such a system invariably invites trouble and eventually brings a shortage in yield through the development of plant diseases or the multiplication of insect pests. A few men have recognized the serious possibilities of such a condition and are endeavoring to modify this method of cropping. (Figs. 4 and 5.)

LABOR REQUIREMENTS.

Growing sugar beets involves two classes of labor—that furnished by the farmer and his teams, and contract hand labor. Since it is a general practice to hire certain operations done at a stipulated price per acre or per ton, it is customary to report the contract labor in money values. There were several farms in each of these districts, however, on which the hand labor was performed by the operator

and his family. In these instances estimates were obtained with reference to the number of hours required in doing the blocking and thinning, hoeing, pulling, and topping. This phase is discussed in part under the heading "Hand labor on sugar beets."

To determine the total requirements for this crop, including hand labor, the records giving estimates on hand labor alone have been used. Table XX gives the labor in producing an acre of sugar beets. A separation has been made in this table for the purpose of showing the acre requirement, excluding hand labor. The 10 farms having the highest man-labor requirement in each district have been averaged and the result is given for comparison. Also, the 10 farms having the lowest man-labor requirement in each district have been set up.



FIG. 4.—Sugar beets have been grown for several years on this field. Result: Poor stand, diseased condition, low yield, and high cost per ton.

TABLE XX.—Total labor requirement per acre.

Region.	Number of records.	Acres harvested.	Hours per acre.		Hours per acre, excluding hand labor. ¹					
					Average.		Average of highest 10.		Average of lowest 10.	
			Man.	Horse.	Man.	Horse.	Man.	Horse.	Man.	Horse.
Lehi, Utah.....	44	303.5	181	163	83	163	110	212	61	122
Garland, Utah.....	58	766	129	136	56	136	81	175	45	118
Idaho Falls and Blackfoot, Idaho.	74	892.3	119	105	52	105	81	147	37	83
Twin Falls, Idaho.....	44	687.03	133	110	56	110	78	129	44	94

¹ Hand labor includes blocking and thinning, hoeing, and topping.

In general, the total man-labor requirement is approximately the same in this investigation as the total requirement given in 1915-16. In the former study Garland operators reported a total of 133.3 man-hours per acre, whereas in this study the total requirement is

given as 129 hours per acre. In the Idaho Falls area the total man-labor requirement for the initial study was 119.4 hours per acre, whereas in this study it is given as 119 hours. In the Provo area, which can be compared with the Lehi district, the total man-labor requirement was 130.8 hours per acre in 1915-16, whereas in this investigation the total for the Lehi district was 181 hours per acre. It may be stated that the high labor requirement for manuring sugar beets in the Lehi area made the total requirement comparatively high. The average yield in the Provo area was essentially 15 tons in 1915-16, whereas in the Lehi district a yield of 16.1 tons was obtained in 1918. This difference would not appreciably change the labor requirements.



FIG. 5.—Sugar beets grown in rotation, and receiving applications of farm manure at regular intervals. Result: Good stand, healthy condition, high yield, and low cost per ton.

The horse-labor requirements were somewhat lower in 1914-15 than in the current survey. These increases for the respective districts are distributed quite uniformly over the preparatory operations, such as plowing, leveling, harrowing, etc. Evidently somewhat more time was necessary to bring the soil into suitable condition than in the former years.

LABOR REQUIREMENTS, BY OPERATIONS.

In compiling the tables which include the normal time for each field operation the average crew size has been used. This item requires a brief explanation. When all farms within a given district are brought together, crews of various sizes will be found within the group. The degree of variation will depend largely upon the type of operation. Cultivating will not include more than two crews as a rule. These will usually consist of one man and one horse and one

man and two horses. Such operations as plowing, harrowing, and leveling may involve several crew sizes. In computing averages for these different groups, fractions appear in the horse column. The prevalence of certain crew sizes always exerts considerable influence upon the average which is obtained. In these tables the most common crew sizes found in each district, as well as the average sizes, are shown. (Tables XXI to XXIV.)

PREPARATORY WORK.

The preparation of the seed bed for any crop grown under irrigation frequently calls for special work to insure a uniform distribution of water when the proper season arrives. An uneven surface inter-

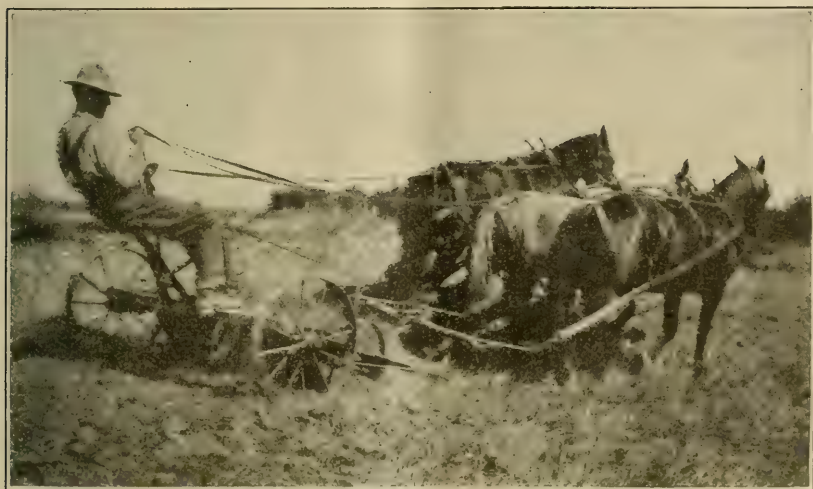


FIG. 6.—Scraping land with a riding fresno.

feres with the run of water and prevents a portion of the field from receiving the amount which is required by the crop to produce the usual yield. It is the custom in all of these districts to level the cultivated area with a scraper of one type or another. Ordinarily a few days are spent during the fall and winter months with the team and scraper at this particular task. (Fig. 6.) In this study scraping the land has been considered improvement work, and while a small amount of man and horse labor was shown on some of these records no charge for this operation was made against the beet crop. It was agreed that this expense should be distributed through a series of years and this process renders the cost for a single crop season practically negligible. Such work merely adds to the farm capitalization, and any costs that may accrue will be taken care of in the distribution of general farm expense to the several enterprises of the business.

TABLE XXI.—*Normal time, by operations, in producing sugar beets—Lehi district, Utah (1918).*

Operation.	Per cent age of total re-cords.	Total acres covered.	Per cent age of total acre-age covered.	Average crew.		Most common crew.		Rate per day.	Times over.	Average hours per acre.	
				Man.	Horse.	Man.	Horse.			Man.	Horse.
Manure.....	93	204.5	65	1.1	2.0	1	2	4.7 loads..	.....	34.7	68.9
Plow.....	100	312.5	100	1.0	3.1	1	3	1.6 acres..	.....	6.6	20.1
Harrow (spike).....	100	312.5	100	1.0	2.9	1	3	9.8 acres..	3.5	3.6	10.6
Level.....	100	312.5	100	1.0	3.1	1	3	7.6 acres..	2.2	2.9	8.7
Harrow (spring).....	41	142	45	1.0	3.1	1	3	4.7 acres..	1.4	2.9	9.0
Roll before plant.....	2	3.5	1	1.0	2.0	1	2	10 acres..	1.0	1.1	2.2
Disk (one-half lap).....	7	15.5	5	1.0	3.3	1	3	1.9 acres..	1.0	3.0	9.3
Plant.....	100	312.5	a 100	.....	.....	.....	.....	.....	.....	.....	.....
Roll after plant.....	75	240.5	77	1.0	2.0	1	2	11.4 acres..	1.0	.8	1.6
Cultivate.....	100	303.5	97	1.0	1.1	1	1	4.9 acres..	4.8	9.5	10.2
Ditch.....	59	198	63	1.1	2.0	1	2	.....	1.0	.6	1.1
Ditch (man only).....	98	307.5	98	1.0	.....	1	.....	2.9 acres..	1.1	3.5	.....
Furrow.....	100	303.5	97	1.0	1.1	1	1	5.7 acres..	1.9	3.3	3.5
Irrigate.....	100	303.5	97	1.0	.....	.....	.....	5.1 acres..	5.9	12.3	.....
Block and thin.....	100	b 304.5	100	1.0	.....	.....	.....	.29 acres..	1.0	36.4	.....
Hoe.....	100	303.5	100	1.0	.....	.....	.....	.8 acres..	.....	.....	.....
Pull weeds.....	20	45.5	15	1.0	.....	.....	.....	1.0 acres..	2.2	27.4	.....
Lift.....	100	303.5	100	1.0	2.8	1	3	.9 acres..	.....	.....	.....
Top and load.....	100	303.5	100	1.2	.....	.....	.....	1.4 acres..	1.1	9.1	.....
Haul.....	100	303.5	100	1.0	2.9	1	3	5.7 tons..	1.0	6.5	17.9
								9.8 tons..	1.0	30.7	.....
									1.0	17.8	50.8

a The planting in this district was done on a contract basis; consequently the average crew size and labor requirements for this operation are not given.

b One acre abandoned after blocking and thinning.

TABLE XXII.—*Normal time, by operations, in producing sugar beets—Garland and Tremonton districts, Utah (1918).*

Operation.	Per cent age of total re-cords.	Total acres covered.	Per cent age of total acre-age covered.	Average crew.		Most common crew.		Rate per day.	Times over.	Average hours per acre.	
				Man.	Horse.	Man.	Horse.			Man.	Horse.
Manure.....	91	317.5	41	1.6	2.8	1	2	13.3 loads..	1.0	17.3	34.7
Plow.....	98	739	96	1.0	3.4	1	3	1.95 acres..	1.03	5.5	18.3
Crown alfalfa.....	10	35	5	1.0	3.2	1	3	1.25 acres..	1.0	7.8	23.7
Harrow (spike).....	100	769	100	1.0	3.5	1	4	13.2 acres..	3.2	2.5	8.2
Level.....	100	770	100	1.0	3.7	1	4	10.1 acres..	2.0	1.9	7.0
Harrow (spring).....	50	316	41	1.1	3.7	1	4	7.5 acres..	1.6	2.1	7.1
Disk (one-half lap).....	3	16	2	1.0	4.0	1	4	5.5 acres..	2.5	4.0	16.0
Disk (no lap).....	17	108.5	14	1.0	4.0	1	4	9 acres..	1.8	2.1	8.4
Float.....	3	30.5	4	1.0	3.0	1	3	10 acres..	1.0	.8	2.4
Roll.....	12	105	14	1.0	2.3	1	2	12.8 acres..	1.1	1.0	2.2
Drag.....	2	8	1	1.0	4.0	1	4	8 acres..	1.0	1.2	4.8
Plant.....	100	772	100	.....	.....	.....	.....	.....	1.1	(a)	(a)
Roll after plant.....	76	538.5	70	1.0	2.0	1	2	12.5 acres..	1.1	.9	1.8
Cultivate.....	95	740	96	1.0	1.9	1	2	9.2 acres..	4.6	5.1	9.8
Ditch.....	86	700	91	1.4	2.2	1	2	20 acres..	1.2	.7	1.2
Ditch (man labor).....	83	623	81	1.1	.....	1	.....	9.8 acres..	1.9	2.0	.....
Furrow.....	95	740	96	1.0	2.0	1	2	10.3 acres..	1.7	1.7	3.4
Irrigate.....	100	772	100	1.0	.....	.....	.....	8.8 acres..	4.6	8.8	.....
Irrigate (replant).....	3	32	4	.....	.....	.....	.....	.....	.....	.....	.....
Replant b.....	7	42	5	1.0	2.0	1	2	7.7 acres..	.....	1.0	2.0
Block and thin.....	100	768	100	1.0	.....	.....	.....	.5 acres..	1.0	23.0	.....
Hoe.....	100	c 768	100	1.1	.....	.....	.....	1.3 acres..	2.3	18.3	.....
Pull weeds.....	17	126.5	16	1.0	.....	.....	.....	1.7 acres..	.....	.....	.....
Lift.....	100	766	100	1.0	3.2	1	3	2.1 acres..	1.3	6.8	.....
Top and load.....	100	766	100	1.2	.....	.....	.....	2.8 acres..	1.0	5.1	16.0
Top, machine.....	2	19	2	1.0	2.0	.....	.....	5.7 tons..	1.0	30.8	.....
Haul.....	100	766	100	1.0	3.7	1	4	2.5 acres..	1.0	4.0	8.0
								12.3 tons..	.....	14.6	51.8

a The planting in this district was done by contract; consequently the average crew size and labor requirements for this operation are not given.

b Only replanting done by direct labor.

c Two acres abandoned after hoeing.

TABLE XXIII.—Normal time, by operations, in producing sugar beets—Idaho Falls and Blackfoot districts, Idaho (1918).

Operation.	Per cent age of total records.	Total acres covered.	Per cent age of total acreage covered.	Average crew		Most common crew.		Rate per day.	Times over.	Average hours per acre.	
				Man.	Horse.	Man.	Horse.			Man.	Horse.
Remove and burn trash.....	7	35	4	1.0	2.0	1	2	15 acres...	1.0	1.1	2.2
Do. ^a	3	21	2	1.0	—	1	—	—	1.0	.5	—
Manure.....	95	600	62	1.6	2.7	1	2	15.1 loads...	1.0	14.9	26.1
Plow.....	96	931.05	96	1.0	3.2	1	3	2.1 acres...	1.0	4.9	15.2
Crown alfalfa.....	1	10	1	1.0	3.0	1	3	2 acres...	1.0	5.0	15.0
Harrow (spike).....	99	957.3	99	1.0	3.1	1	3	13.7 acres...	3.88	2.8	8.8
Level.....	89	838.05	87	1.0	3.5	1	4	10.8 acres...	1.67	1.7	5.7
Harrow (spring).....	20	110.25	11	1.0	3.5	1	4	6.4 acres...	1.64	2.4	8.4
Disk (one-half lap).....	4	15.5	2	1.0	3.0	—	—	4 acres...	1.33	3.0	8.1
Disk (no lap).....	8	56	6	1.0	3.7	1	4	6.5 acres...	2.0	2.9	10.7
Float.....	32	301	31	1.0	3.0	1	3	11.75 acres...	1.60	1.3	4.0
Roll.....	38	429	44	1.0	2.2	1	2	14.5 acres...	1.07	.8	1.7
Plant.....	100	967.3	100	1.0	2.0	1	2	10.4 acres...	1.1	1.1	2.2
Harrow after plant.....	1	1.5	(^b)	1.0	3.0	1	3	3 acres...	2.0	6.7	20.1
Roll after plant.....	39	308.3	32	1.0	2.0	1	2	14.6 acres...	1.07	.8	1.6
Cultivate.....	100	892.3	100	1.0	1.9	1	2	8.7 acres...	4.46	5.7	10.7
Ditch.....	47	514.5	53	1.7	2.5	2	2	—	1.0	.9	1.4
Ditch (man only).....	92	883.3	91	1.1	—	1	—	—	1.29	1.6	—
Furrow.....	100	892.3	100	1.0	1.9	1	2	9.8 acres...	1.64	1.9	3.5
Irrigate.....	100	892.3	100	1.0	—	—	—	7.5 acres...	5.01	12.6	—
Block and thin.....	100	898.3	100	1.3	—	—	—	.67 acres...	1.0	21.9	—
Hoe.....	100	898.3	100	1.4	—	—	—	2 acres...	2.1	16.9	—
								2.3 acres...			
								4.1 acres...			
Pull weeds.....	7	66	8	1.0	—	—	—	1.5 acres...	1.25	7.4	—
Lift.....	100	892.3	100	1.0	2.8	1	3	2.2 acres...	—	4.6	12.9
Top and load.....	100	892.3	100	1.8	—	—	—	7.8 tons...	—	28.4	—
Haul.....	100	892.3	100	1.0	3.3	1	4	11.7 tons...	—	10.8	34.5

^a Man hours only. ^b Less than 1 per cent. ^c Six acres abandoned after blocking, thinning, and hoeing.

TABLE XXIV.—Normal time, by operations, in producing sugar beets—Twin Falls district, Idaho (1919).

Operation.	Per cent age of total records.	Total acres covered.	Per cent age of total acreage covered.	Average crew		Most common crew.		Rate per day.	Times over.	Hours per acre.	
				Man.	Horse.	Man.	Horse.			Man.	Horse.
Remove trash.....	7	13.5	2	1.0	2.0	1	2	—	1.0	0.8	1.6
Manure.....	48	276.7	40	1.4	2.5	1	2	12.8 loads...	1.0	14.4	27.3
Plow.....	95	661.03	96	1.0	3.4	1	3	2.1 acres...	1.05	5.2	17.0
Crown alfalfa.....	23	133.75	19	1.0	3.8	1	4	2.6 acres...	1.0	3.8	14.3
Harrow (spike).....	98	682.03	99	1.0	3.2	1	3	15.6 acres...	3.40	2.3	7.2
Level.....	80	516.03	75	1.0	3.3	1	4	8.4 acres...	2.02	2.6	8.1
Harrow (spring).....	48	365.75	53	1.0	3.3	1	3	8.6 acres...	2.07	2.4	8.2
Disk.....	43	356.2	52	1.0	3.3	1	3	7.9 acres...	2.32	3.8	10.8
Float.....	32	309.75	45	1.0	3.2	1	4	12.8 acres...	1.86	1.6	5.5
Roll before plant.....	75	534.20	78	1.0	2.1	1	2	10.5 acres...	1.09	1.1	2.2
Plant.....	100	687.03	100	1.0	2.0	1	2	8.6 acres...	1.10	1.3	2.6
Harrow after plant.....	2	16.25	2	1.0	2.0	1	2	—	3.0	2.8	5.6
Roll after plant.....	36	275.25	40	1.0	2.1	1	2	11.6 acres...	1.31	1.1	2.3
Plank.....	5	12.5	2	1.0	2.0	1	2	15 acres...	1.50	.9	1.8
Cultivate.....	100	687.03	100	1.1	1.9	1	2	7.7 acres...	4.42	6.9	12.3
Ditch (man and horse).....	7	50	7	1.3	2.0	1	2	—	1.0	.5	.8
Ditch (man only).....	86	641.28	93	1.0	—	1	—	4.8 acres...	1.0	1.5	—
Furrow.....	100	687.03	100	1.0	1.9	1	2	8.3 acres...	2.25	3.4	6.1
Irrigate.....	100	687.03	100	1.0	—	—	—	—	4.68	15.6	—
Block and thin.....	100	687.03	100	3.0	—	—	—	.9 acre...	1.0	28.0	—
Hoe.....	98	687.03	100	1.7	—	—	—	1.8 acres...	2.0	22.3	—
								1.7 acres...			
								2.3 acres...			
Lift.....	100	687.03	100	1.0	2.8	1	3	2.2 acres...	—	4.6	12.7
Top and load.....	100	687.03	100	2.0	—	—	—	6.8 tons...	—	21.9	—
Haul.....	100	687.03	100	1.0	3.0	1	2	13.1 tons...	—	8.7	22.9

REMOVING AND BURNING TRASH.

In two districts a small amount of work was devoted to removal of trash following the harvest of the preceding crop. In the Idaho Falls area 4 per cent of the acreage planted to beets had trash removed from it; in the Twin Falls district, 2 per cent.

APPLICATION OF MANURE.

Farm manure was applied to 65 per cent of the total beet acreage of the farms visited in Lehi district, 62 per cent in the Idaho Falls area, and 40 per cent at Garland and at Twin Falls. In the Lehi area the manure was hauled almost exclusively with wagons and the application was made during the fall and winter months. The most common crew consisted of one man and two horses. In the Garland district slightly more than half of the men used manure spreaders and approximately two-thirds of the work was done during the fall and winter. There was considerable variation in the crew sizes in this district. Essentially the same methods were employed in the Idaho Falls and Twin Falls area, although the larger number of farmers made use of the manure spreader in the latter district.

As a rule beet growers can give very reliable estimates on the number of loads of manure applied per acre and the number of loads hauled per day. It is much more difficult to ascertain the number of tons applied per acre. Manure is never weighed, and as it varies somewhat in quality, as well as in the quantity of moisture that it contains, estimates on the per-ton application are likely to be exceedingly variable. In view of these facts it was felt that it would be best to report on the load basis. In the Lehi area the average application was given as 14.5 loads per acre. At Garland the average application was 12.5 loads, at Idaho Falls 13 loads, and at Twin Falls 12.2 loads per acre.

The man and horse labor requirements for manuring are influenced to some extent by the hauling distances, the size of the crew, and the condition of the field. In the Lehi district the labor requirement was comparatively high, because the average hauling distance was somewhat greater than in the other districts studied. Since many operators live in town and maintain some stock there, manure is frequently hauled from town to farm.

PLOWING.

The beet land is given only one plowing on the average farm, although two plowings are sometimes necessary.

In view of the fact that the sugar-beet crops followed alfalfa in three of these districts, a small amount of "crowning" was necessary. Crowning means breaking to a depth of 3 or 4 inches, which is suffi-

cient to cut the crowns of the alfalfa plants. The tops are then allowed to dry out and the ground is replowed at a later date to a depth of 8 or 9 inches. Crowning alfalfa occurred on 8 per cent of the land planted to beets in the Garland area. Two and three-tenths per cent of the beet land was crowned at Idaho Falls, and as much as 22 per cent in the Twin Falls area, where the labor requirements for this operation were only slightly less than the labor for plowing. However, in the Garland district the reverse was the case.

Occasionally plowing is repeated in order to bring rough or uneven land into suitable condition for planting. Two plowings were necessary apparently in those cases where the ground was crowned and later given a deeper plowing in preparation for sugar beets. The work was divided quite largely between the autumn and spring seasons. The usual depth of plowing was approximately 9 to 10 inches.

There was considerable variation in the types of plows that were used. In the Lehi area the work was done mainly with sulky plows, the usual crew consisting of one man and three horses. Three types were used at Garland—namely, walking plows, sulky plows, and two-way plows. The most common crew was one man and three horses. The riding sulky plows were used quite extensively at Idaho Falls, whereas at Twin Falls two-way plows were used quite generally. The crew size was the same for both of the latter areas, consisting of one man and three horses. Plowing was done at an average rate of from 1.6 acres per day to 2.1 acres per day. The average rate for crowning was approximately 2.6 acres per day in the Twin Falls area. A day's work in all of these districts approximated nine and one-half hours.

The majority of the beet growers harrowed daily all of the land that was broken out that day. Fall-plowed land is liable to wind drift in this region. Many operators made a practice of harrowing up to the plow each half day, to prevent undue evaporation of moisture. This practice leaves the surface of the field in much better tilth, and subsequent culture can be carried out much more effectively than when the land is allowed to dry out before harrowing. The hot sun and rapid evaporation of moisture is likely to form hard clods if harrowing is not done soon after plowing.

In the preparation of land the disk harrow was used on relatively few farms in the Lehi, Garland, and Idaho Falls districts, but approximately 52 per cent of the area planted to beets in the Twin Falls district was disked. The operators on these farms went over the land an average of 2.3 times. On some farms it was customary to lap half when going over the field. Where this practice was common the two methods, single disk and lap half, have been separated, and the man and horse labor requirements are shown for each method. When the land is rough and cloddy after plowing and harrowing it

can be pulverized and placed in condition much more readily with the disk harrow than with any other implement.

In the 1915-16 survey, just as in the current survey, comparatively few farmers gave estimates on disking.

LEVELING.

The leveler is almost indispensable on an irrigated farm. It is usually homemade, a frame of planks on edge, and the original cost should not exceed the actual cash outlay for the timber, bolts, and rods which are used in its construction. Although the primary object is to bring the surface to an even grade, more is accomplished than actually leveling the plowed soil. The leveler serves to break or crush many clods and also firms the seed bed. In this way leveling assists in securing the degree of pulverization essential in a good seed bed.

In the order of operations, leveling occupies an intermediate place between plowing and planting. Essentially the entire beet acreage was gone over with this implement. Exceptions may be found on farms in the Idaho Falls and Twin Falls districts. It will be noted, however, that floating the land was much more common in these two districts than at Lehi and Garland. The latter operation undoubtedly took the place of leveling.

The most common crew for leveling in the Lehi area consisted of one man and three horses. In the remaining districts the usual crew was one man and four horses. Leveling was done at the rate of 8 to 10 acres per day.

FLOATING.

The float is designed primarily to crush clods (fig. 7) and firm the ground, but it does not leave the land in as good condition for irrigation as does the leveler. It is constructed out of planks lapped one upon another, forming a stepped surface that comes in contact with the soil. The average width of this implement is approximately 8 feet. This homemade device is often attached to the rear of the harrow. Occasionally the same result may be obtained by affixing a single plank behind the harrow. The usual crew consisted of one man and three horses. Approximately 10 to 13 acres per day were covered with this implement.

HARROWING.

The toothed harrow is an important tillage implement on every farm. It is not only used extensively in the preparation of land which is to be seeded to grain, but it also plays a very important part in the development of a suitable seed bed for intertilled crops. Two types were found in these districts, namely, the common spike-tooth harrow and the spring-tooth harrow.

The usual crew size was one man and three horses, but Garland growers utilized a crew consisting of one man and four horses. Average "times over" ranged from 3.2 for Garland to 3.8 for Idaho Falls.

The spring-tooth harrow was used much less in all of these areas than the spike-tooth. The most common crew sizes were essentially the same as for the spike-tooth.

ROLLING.

Beet growers roll prior to planting for the purpose of creating a smooth, even surface for the drill. To get straight rows the driver must see the trail which has been left by the marker, and this line



FIG. 7.—A float used on sandy soil for the purpose of breaking clods and creating a level surface ahead of the drill. Here the crew consists of one man and two horses, whereas the usual crew includes one man and three horses.

can be distinguished most readily on a newly rolled field. Furthermore, a firm and smooth seed bed is essential for planting at an even depth. Under certain conditions the roller may be operated for the purpose of breaking down a cloddy surface, or it may be utilized to break a crust after rain when the young plants are pushing through the surface. This operation is known as "rolling beets." Rolling the land before cultivation, especially before the blocking and thinning are done, facilitates the latter operation, and undoubtedly aids in removing many small obstructions, such as soil lumps, that may interfere with handwork. Rolling after thinning and before the next cultivation is sometimes done to prevent the covering of small beets

by loose dirt thrown in a ridge between the rows, especially where double-row thinning is practiced. These two operations are shown separately in the tables.

It will be seen that in the Lehi and Garland districts rolling after planting is much more important than rolling before planting. In the Idaho Falls area, where the soil type is lighter, about the same percentage of beet acreage was rolled before planting as after. In the Twin Falls area more rolling was done before planting than after. The most common crew for this operation consisted of one man and two horses. Rolling is usually done at the rate of 8 to 12 acres per day.

DITCHING.

A certain amount of ditching must be done annually on an irrigated farm. This may include work on the lateral which carries water from the main canal to the farm proper, or it may involve the removal of silt or other débris from the distributing lateral, or the building of temporary laterals. Whatever work is done should be divided equally among those enterprises with which the operation is directly chargeable. Sugar beets should bear a fair proportion of this cost.

This cleaning does not require much time; consequently, the total charge is small. In some cases the operation includes both man and horse labor. In others the work involves hand labor only. Frequently a plow may be used to advantage in removing the accumulated silt from the bottom of the lateral. A V-shaped machine is sometimes substituted for or used after the plow. The ditching is usually done immediately preceding a run of water.

In getting estimates on ditching practice only such work as the operator applied directly to the beet crop was entered in the record. These data were tabulated in two classes, the first comprising figures from those farms where man labor only was involved, the second figures from farms using both man and horse labor. Some growers did a part of the ditching with man and horse labor and completed the operation with hand labor only.

In the Lehi district ditching was done on 63 per cent of the acreage with man and horse labor. Man labor alone was applied to 97 per cent of the acreage. In the Garland district both classes of work apply to practically all of the beet acreage. In Idaho Falls 53 per cent of the acreage was included under ditching where man and horse labor were used, while 91 per cent of the acreage included man labor only. Man and horse labor for ditching in the Twin Falls district constituted a minor item.

PLANTING.

In the beet-growing districts of Utah it is customary for the factories to own and operate the beet drills. Ordinarily the planting is not done by the individual grower, but by some person employed by the sugar company to do this work on a number of farms within a given area. The men engaged for this purpose usually have small farms and are therefore in a position to do some outside work. There are several advantages in this arrangement. It is very evident that a man who operates a beet drill regularly can do a better grade of work than the man who plants a six or eight acre tract, which requires a fraction of a day, or at most not more than

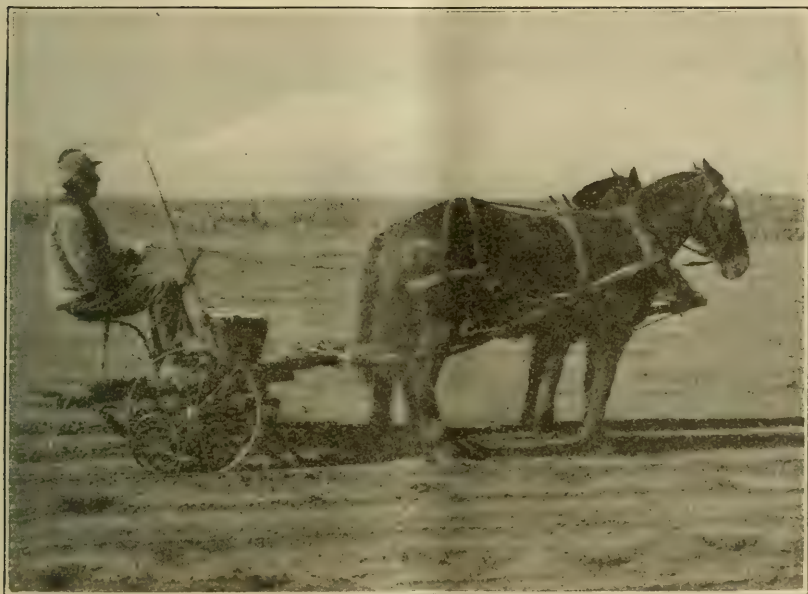


FIG. 8.—Putting in beet seed with a 4-row drill.

a full day, per year. Furthermore, the small farmer is not required to carry an investment in a piece of machinery which is used only for a few hours each year.

A direct charge of 50 cents per acre is made to cover the cost of planting. Beet seed is sold to the farmers at the rate of 15 cents per pound, and approximately 15 pounds are planted per acre. The farm operator hauls the seed from the factory or warehouse to the farm. This work is done at a season of the year when farm work is not pressing, or it is made a secondary feature of some special trip to town. The item of hauling seed is cared for under "overhead expense." In the Idaho district the farmers did their own planting. Beet seed is universally put in with a 4-row drill. It requires one

man and two horses to do this work. (Fig. 8.) From 8 to 10 acres can be planted per day.

Frequently a portion of a stand may be lost and it becomes necessary to replant a part of the acreage. Replanting occurred on 54 acres in the Idaho Falls and Blackfoot area and on 48 acres in the Twin Falls area.

CULTIVATING.

Cultivation of sugar beets begins from two and one-half to three weeks after planting. The crop then receives attention at frequent intervals during the month of June and early in July. Cultivation usually ceases when the tops cover the space between the rows. Usually all of the cultivation is completed before irrigation, though under certain conditions there may be overlapping. Blocking and



FIG. 9.—Cultivating sugar beets with a crew of one man and two horses. Four rows are handled by this cultivator.

thinning proceeds simultaneously with the first cultivation. (See "Hand labor.")

In the Lehi district the cultivating was done almost entirely by a crew consisting of one man and one horse. On the average, beets were cultivated about five times. The most common crew in the three remaining areas consisted of one man and two horses. (Fig. 9.) In the Lehi district approximately 5 acres were cultivated per day, and in the other areas the average ground covered per day varied from 7.7 to 9.2 acres. The difference is reflected in the man-labor cost for cultivating and furrowing in the Lehi district. The 4-row cultivator, with its crew of one man and two horses, assists in reducing the number of man-hours expended per acre, and this, in turn, influences the total cost per acre.

OPENING FURROWS.

Furrowing is the opening up of furrows between the beet rows to make ready for irrigation. The furrowing is usually done after the last cultivation, with special attachments which are provided with each beet cultivator.

On many farms it is a custom to run the water in every other row space, alternating with each irrigation, and these are the rows which require special attention at the completion of the last cultivation. There are cases where water is run in every row space. As a rule, it is necessary to furrow out once for the purpose of making ditches and once to clean out and deepen them. The average number of times for furrowing approximated two in the Lehi and Garland



FIG. 10.—Removing a canvas dam in order to permit the head of water to find a new level.

areas, a little more than one and one-half times in the Idaho Falls area, and slightly more than two in the Twin Falls area. The crew sizes for furrowing and the rate per day correspond with the crews and rates for cultivation.

IRRIGATION.

Irrigation requires man labor only. The making of ditches and cleaning of laterals require some horse labor, but this has been included under ditching. On most farms where sugar beets are grown, water is supplied by surface irrigation. There are a few farms that have subirrigation or seepage water that raises the water table in the soil high enough to supply the beet crop; but these fields are very rare and are not generally considered as areas producing normal sugar beet crops. Some men grow sugar beets with only one application of irrigation water, but this is usually done only where the

available supply of water is low. Most lands in this region, to produce a normal yield of sugar beets, need two to four or more irrigations per growing season.

In the Lehi district 3 per cent of the acreage of sugar beets was not irrigated. In all of the other regions all of the acreage received one or more irrigations. Water was applied, on the average, six times per season on the Lehi fields, and about five times at Garland, Idaho Falls, and Twin Falls. (Fig. 10.) The irrigation season extended from May to the latter part of September. The available supply of water determines the number of irrigations applied in the latter part of the growing season, as most men believe that late irrigation increases the yields. When the soil is too dry at planting time, the growers either irrigate the land before planting or furrow irrigate immediately after planting. Then the crop is left as long as possible before irrigating the young beets, since a run of water interferes with cultivation and it is somewhat difficult to make furrows between the rows of small beets without covering some of the young plants. It is also generally assumed that, when young, the beets can stand more drouth without injury than they can later in the season. Where one has water available, the plants should not suffer for water at any time during the season. To obtain maximum yields it is essential that the beets use the entire growing season, and they can not make growth when suffering from lack of moisture.

The man-labor requirement varied somewhat for the different districts, owing to the difference in the acreage irrigated per day and the number of irrigations. The variation is greater between farms in the same region than between the district averages. There are many factors that influence the labor necessary for the irrigation of a given piece of land. The lay of the land and the head of water available are undoubtedly the most important of these factors.

BLOCKING AND THINNING.

Enough beet seed is usually drilled to give more plants than are required, provided a good germination is obtained. As soon as the plants are large enough so that the rows can be distinguished the blocking and thinning is done. Blocking, which means chopping out surplus plants with the hoe, leaves small clusters of beets ten to twelve inches apart in the row. Thinning, which is done by hand, takes out the surplus plants in each cluster. On a small farm the operator, with the assistance of members of the family, does part or all of this work.

In the Lehi area 90 per cent of this work was handled by the operator and his family. The rest represented contract labor for the handwork. In the Garland district 80 per cent was handled by the operator and his family. In the Twin Falls area essentially

85 per cent of the hand labor was done on a contract basis. At Idaho Falls 91 per cent was done by the operator and his family.

HOEING.

Hoeing is done during the early summer months. Under ordinary conditions the fields are hoed twice, but these records show three hoeings for the years 1918 and 1919. In cases where a contract is involved, the hand labor agrees to keep the field free from weeds; this may mean hoeing three times, together with some work in pulling out large weeds late in the season.

The stipulations of a typical agreement for contract labor for the year 1918 are given herewith:

The grower, in consideration of the promises herein contained to be kept and performed by the said contractor, agrees to pay the contractor for said work as follows:

Thinning.....	\$8.00 per acre
First hoeing.....	3.00 per acre
Second hoeing.....	2.00 per acre
Pulling, topping, and loading—8-ton average crop or under.....	12.00 per acre
Pulling, topping, and loading—9-ton average crop.....	13.00 per acre
Pulling, topping, and loading—10-ton average crop.....	14.00 per acre
Pulling, topping, and loading—11-ton average crop.....	15.00 per acre
Pulling, topping, and loading—12-ton average crop.....	16.00 per acre
Pulling, topping, and loading—13-ton average crop.....	17.00 per acre
Pulling, topping, and loading—14-ton average crop.....	18.00 per acre
Pulling, topping, and loading—15-ton average crop.....	19.00 per acre

In case the crop shall exceed 15 tons average per acre, the grower agrees to pay the contractor for harvesting such excess tonnage at the rate of \$1 per ton.

The contractor agrees that out of the money due for thinning the grower shall retain the sum of fifty (50) cents per acre, and out of the money due for first hoeing the sum of fifty (50) cents per acre, as guarantee for the proper completion of the later work. Upon the proper completion of the second hoeing and harvesting, this money shall be repaid to the contractor, without interest.

The grower agrees to pay the contractor promptly upon the completion of each item of work, and, in case of delay in payments, the grower agrees to pay interest on all deferred payments from the time when due until paid at the rate of 1 per cent per month.

* * * * *

In the event that the grower shall elect to pull and top his beets with a mechanical device, he may be released from the further operation of this contract without prejudice, by notifying the contractor of his intention on or before September 1, 1919, and by paying to the contractor the \$1 per acre retained under the above-mentioned arrangement, together with any money due the contractor.

The contractor agrees, where possible, to space the beets from 9 to 14 inches apart in the row, thinning the plants so that not less than 90 per cent thereof shall be single plants at the time of thinning; to leave the plants in a healthy condition, not to expose the roots more than necessary; at thinning time to hoe deep enough to remove all weeds by the roots that are in the row or within three inches thereof on either side; to keep the beets free from weeds in the row by hoeing them at least twice after thinning; if so instructed by the agents of the sugar company, to pull all weeds

by hand at the time of the second hoeing, and to avoid filling up irrigation ditches or furrows where the tops are so large that it will be impossible to refurrow. The contractor agrees to perform said hoeings at the time and in the manner specified.

The contractor further agrees that, at the time of harvest, he will pull the beets by hand and strike them together as much as necessary to remove the dirt, and pile at least six rows of beets in one windrow; that under no condition will the contractor use a hook or any other sharp instrument for pulling the beets; that he will top the beets at the base or bottom leaf; that he will pile the beets upon clear ground free from leaves, weeds, trash, or clods, in piles of from 300 to 400 pounds each, and will load the same into the wagons free from leaves, weeds, trash, or clods of any kind, and as free from dirt as possible; that at the request and under the direction of the grower he will keep the beets thus piled covered with sufficient leaves to protect them thoroughly from frost and sun, it being understood that, if the grower wishes the beets covered with dirt, he will bear the expense thereof, and that the grower



FIG. 11.—Lifting or pulling with a 1-man, 3-horse crew.

will also bear the expense of uncovering and loading all beets that may be covered with leaves or dirt.

The contractor agrees to do all work specified herein promptly, regularly, in a workmanlike manner, and to the satisfaction of the representative of the sugar company.

In the event of the failure of the contractor properly to perform his work at the time and in the manner stipulated, the one dollar (\$1) per acre withheld as aforesaid, or such part thereof as may be equitable and just, shall be forfeited to the grower as liquidated damages for such failure, provided, however, that the agricultural representative of the sugar company having charge of the said tract of land shall have exclusive power and authority to determine whether any such forfeiture shall be made and the extent thereof, notice of the decision to be communicated to the contractor in writing.

The grower agrees that he will properly prepare the land and plant the beets, and, as soon as the rows can be seen, will proceed with the cultivating, exercising care not to cover the beets, and so running the cultivator as to cut all the weeds between the rows; and in the event that other cultivation shall be necessary before thinning, that he will do the same as rapidly as possible so as to prevent delays in the thinning;

and, as soon as the beets have straightened up, that he will proceed to cultivate as often as may be required to remove the weeds between the rows without destroying any of the plants. The grower further agrees to plow up his beets as rapidly as the contractor is able to pull, top, and load the same and to furnish wagons promptly for hauling the same to the sugar company's receiving station.

The grower agrees to furnish the contractor with a camping place for the laborers necessary to perform the work herein provided for, together with hay or straw for their bedding and water and fuel for domestic purposes. In the event that the grower's fields shall be more than one mile from the camp established by the contractor, the grower agrees to haul all laborers necessary to perform the work hereinbefore provided for, to and from such fields. The grower further agrees to haul the laborers from the sugar factory or the railroad station to his farm and to return them at the completion of their work.

LIFTING, PULLING, AND TOPPING.

The harvest season begins late in September and frequently extends well into the month of November. As a rule enough lifting is



FIG. 12.—Topping sugar beets. Sometimes it is customary to pull and top from the loosened row, while in other cases the beets are thrown in piles and topping is done from the latter.

done each day to furnish work for that day. The pulling is done by hand as described in the foregoing contract. The beets covered by this study were loosened entirely with a one-row lifter. (Figs. 11 and 12.) The most common crew for lifting consisted of one man and three horses. From one and one-half to two acres constitutes a day's work in lifting.

The handwork, pulling, and topping, has been described in the sample contract.

HAULING.

Hauling coincides with lifting. When the latter begins late in September or early in October the greater part of the work will be

completed by the middle or toward the end of November. The sugar beet is a bulky and heavy product to handle; hence good wagons with substantial racks are an important part of the grower's equipment. Ample horsepower must be provided to haul the beets from the field to the dump, slicing station, or factory. (Fig. 13.) Formerly many of the sugar beets were unloaded by hand, but under present conditions part of this work is done mechanically. When the soil is soft, an extra team may be required to assist the regular crew.

The distance between the beet fields and the loading station naturally has considerable influence on the cost of delivery. If there is a long haul, the cost of hauling will be much greater than it is for the farm which has a near-by loading station. (Table XXV.)



FIG. 13.—Hauling beets to sugar factory. This type of rack enables the grower to unload without any hand labor and with but little loss of time.

Comparing the group with an average hauling distance of less than one-half mile with the group with an average haul of over 3 miles, it will be seen that there is a difference of 5.5 man-hours and about 22 horse-hours in labor requirements for hauling.

TABLE XXV.—*Relation of distance from market to time required for hauling beets.*

Groups, by distance.	Average distance.	Percentage of records.	Average crew.		Hours per ton.		Hours per acre.	
			Man.	Horse.	Man.	Horse.	Man.	Horse.
Less than 1½ miles.....	0.9	57	1.0	3.3	0.7	2.4	10.09	33.62
1½ to 3 miles.....	2.3	31	1.0	3.2	.9	3.0	12.03	38.72
Over 3 miles.....	3.8	12	1.0	3.6	1.1	3.8	15.59	55.91

COMPARISON OF BEET RECEIPTS WITH OTHER FARM RECEIPTS.

A comparison of the returns from sugar beets with that from other farm enterprises brings out the importance of this crop in these districts. By referring to Table XXVI it will be seen that the per cent of farm receipts from sugar beets varied considerably on the 220 farms surveyed. In the Twin Falls area approximately 25 per cent of the farm receipts were from sugar beets, whereas in the Lehi and Garland districts approximately 50 per cent of the farm receipts came from the sale of sugar beets. The Idaho Falls farms fell between these extremes. In all cases the major portion of the farm incomes came from the sale of crops. The Idaho Falls and Twin Falls areas indicate returns from live stock and live-stock products ranging from 17 to 23 per cent.

In the Lehi and Garland districts about 63 per cent of the income from crops came from sugar beets. The percentage was somewhat lower in the Idaho Falls and Twin Falls areas. In the latter districts potatoes and wheat were important cash crops.

TABLE XXVI.—*Per cent of receipts from various sources.*

Region.	Percentage of farm receipts.					Percentage of crop receipts.	
	From beets.	From beet tops.	From all other crops.	From live stock and live-stock products.	From miscellaneous crops.	From beets.	From beet tops.
Garland, Utah.....	53.5	1.5	29.1	13.6	2.3	63.6	1.7
Lehi, Utah.....	48.2	1.9	27.1	17.5	5.3	62.4	2.4
Idaho Falls and Blackfoot, Idaho.....	34.3	1.2	40.4	23.2	.9	45.2	1.6
Twin Falls, Idaho.....	26.4	1.1	49.6	16.9	6.0	34.2	1.4

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L. O. HOWARD, Chief



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PROFESSIONAL PAPER

September 20, 1921

GARDEN FLEA-HOPPER IN ALFALFA AND ITS CONTROL.

By A. H. BEYER, *Scientific Assistant, Cereal and Forage Insect Investigations.*

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INTRODUCTION.

Little information has been recorded regarding the biology, habits, and control of *Halticus citri*, known as the garden flea-hopper. Dr. F. H. Chittenden was the first to attach to *Halticus citri* (Ashmead), then known as *Halticus uhleri* (Giard), the common name, chosen because of the insect's injuries to truck crops and its saltatory power.

In addition to other leguminous plants the insect attacks alfalfa, injuring the plant by sucking the juices, and in fields where heavy infestation occurs may cause the loss of 50 to 60 per cent of the crop. As little was known of the insect outside of its depredations on truck crops, observations and life-history studies on the garden flea-hopper on alfalfa were conducted during the years 1915, 1916, and part of 1917, at Columbia, S. C., and also a series of control experiments for the purpose of determining the most effective means of combating outbreaks of the pest. The bulletin, therefore, gives the results accomplished by means of a combination of field and laboratory experiments.

ORIGIN AND DISTRIBUTION.

The present known range of the garden flea-hopper covers a large portion of the United States (fig. 1). This insect belongs to the family Capsidae of the Heteroptera, is quite generally distributed throughout the eastern half of the United States, and in most instances has been reported as injurious to crops.

The garden flea-hopper is apparently American in origin. There are, however, two cases on record where it is reported as being de-

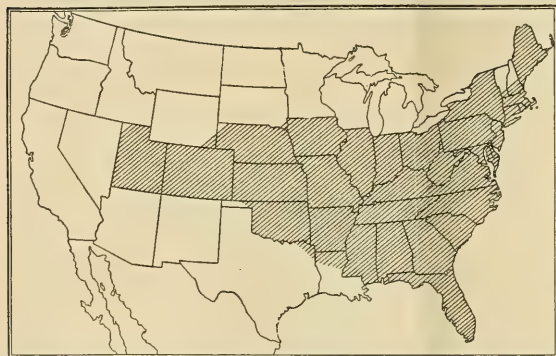


FIG. 1.—Map showing States where the garden flea-hopper (*Halticus citri*) has been found.

structive to crops outside of the United States, viz, Brazil and French Cochin China. In the latter region it seriously infested the peanut crop.¹

During the summer of 1916 the writer made numerous observations with a view of determining what effect altitude might have upon the dis-

tribution of this species. Sweepings made at the points mentioned below showed the presence of the adults and nymphs in the highest as well as the lowest altitudes where collections were made. The trip included visits during the month of August, 1916, to alfalfa and clover fields at Macon, Ga.; Gray, Ga.; Sylva, N. C.; Waynesville, N. C.; Asheville, N. C.; Statesville, N. C.; Columbia, S. C.; and Gainesville, Fla. The territory covering these points included a range of altitude from 180 feet to 2,700 feet. Gray, Ga., which has an altitude of 500 feet, was the center of the 1915 outbreak.

¹ The following notes on the garden flea-hopper (*Halticus citri*) and list of localities have been compiled from field studies in the United States and from specimens contained in the collections of the U. S. National Museum: Orange Springs, Fla., 1887 (W. H. Ashmead); Riley Co., Kans., Sept. 10, 1892 (C. L. Marlatt); Washington, D. C., June 22, 1897; Columbia, Mo., no date (C. V. Riley); Berkeley Springs, W. Va. (P. R. Uhler); Auburn, Ala., no date (P. R. Uhler); Experiment Station, Manhattan, Kans., 1889 (E. A. Smith); Experiment Station, Hartford, Conn., Sept., 1914 (W. E. Britton); Stillwater, Okla., Oct., 1912 (C. E. Sanborn); Topeka, Kans., Aug. 30, 1917 (E. A. Popenoe); Chicago, Ill., July 13, 1908 (J. J. Davis); Clemson College, S. C., July 16, 1909 (G. G. Ainslie); Nashville, Tenn., Sept. 5, 1910 (G. G. Ainslie); Experiment Station, Utah, 1893 (P. R. Uhler); Winchester, Va., July 13, 1913 (E. B. Blakeslee); Washington, D. C., 1917 (F. H. Chittenden); Gray, Ga., 1915 (R. J. Stewart); Gray, Ga., May 26, 1915 (A. H. Beyer); Macon, Ga., May 27, 1915 (A. H. Beyer); Lafayette, Ind., Aug. 11, 1916 (J. J. Davis); Atlanta, Ga., Aug. 25, 1916 (A. H. Beyer); Statesville, N. C., Aug. 31, 1916, Waynesville, N. C., Aug. 27, 1916 (A. H. Beyer); Asheville, N. C., Aug. 28, 1916 (A. H. Beyer); Charlotte, N. C., Aug. 31, 1916 (A. H. Beyer); Hagerstown, Md., Sept. 12, 1912 (H. L. Parker); Columbia, S. C., Oct. 5, 1915 (A. H. Beyer); Ithaca, N. Y., Oct., 1915 (H. H. Knight); Boston, Mass., Sept., 1915 (H. H. Knight); Springfield, Mo., July, 1915 (H. H. Knight); Quincy, Fla., May 23, 1916 (F. H. McDonough); Lakeland, Fla., Dec. 16, 1916 (A. H. Beyer); Fulton Co., N. Y., Aug., 1911 (C. P. Alexander); Indianapolis, Ind., Aug. 25, 1916 (H. F. Dietz); Gainesville, Fla., Feb. 28, 1917 (A. H. Beyer); Charleston, Mo., May 26, 1916 (E. H. Gibson); Hot Springs, Ark., May, 1916 (E. H. Gibson); Chapel Hill, N. C., Sept. 21, 1915 (P. Luginbill).

P. R. Uhler (5)² recorded the garden flea-hopper as having been found at the experiment station at Logan, Utah, which point has an approximate altitude of 4,700 feet above sea level.

SYNONYMY.

The garden flea-hopper was first named and described by Ashmead (1) as *Rhinocloa citri*. E. A. Popenoe (2) in 1890 called it "*Halticus minutus* Uhler MS." During the same year Giard (3) renamed the species *uhleri*, since there was already a *Halticus minutus* Reuter. Distant (4, p. 430) in 1893 redescribed the species as *Calocoris canus*, not recognizing its true affinities.

Reuter (12) in 1909 first pointed out that *Rhinocloa citri* Ashmead and *Halticus uhleri* Giard were the same, but he left the species under the latter name until 1914, when H. G. Barber (15) used the combination "*Halticus citri* (Ashm.)" in print.

The synonymy, therefore, is as follows:

***Halticus citri* (Ashmead) Barber.**

Rhinocloa citri Ashmead (1).

Halticus minutus (Uhler MS) Popenoe (2).

Halticus uhleri Giard (3).

Calocoris canus Distant (4).

Halticus citri Barber (15).

HISTORY OF THE SPECIES AND ITS INJURIES.

Halticus citri seems first to have received economic mention in 1887, by W. H. Ashmead (1), who found it on orange trees in Florida.

In 1892 A. Giard (3) recorded it as being destructive to peanut and rice crops of French Cochinchina and Singapore, Straits Settlements.

This species, with *Agalliastes bractatus* Say, was reported from Kansas in 1890 (2) as follows:

We have the past season observed two species of Capsidæ, or plant-bugs, living in great numbers on the underside of the leaves of the garden bean, puncturing the tissues and sucking the sap, and by these punctures causing the death of the tissues in small, irregular patches, that appear upon the upper surface of the leaf as white spots.

It was found by J. B. Smith (6, p. 133) in New Jersey during 1900 injuring truck crops at the following places: New Brunswick, Jamesburg, Swedesboro, Madison, Camden County, and Vineland.

In 1900 F. M. Webster (7) reported it from Wooster, Ohio. F. H. Chittenden (8) states:

In May and June, 1900, this insect was observed in some numbers on beans in different localities, and some leaves were found to have been killed by its attacks. Beets and cabbage were also affected, but injury was less noticeable to these crops. In 1901 the writer noticed severe injury to ornamental morning-glory in the city of Washington.

² Reference is made by number (italic) to "Literature cited," p. 27.

W. E. Britton (9) of Connecticut, during September, 1904, received specimens of the insect from Southport, Conn., with the statement that much injury was being done by it to smilax growing under glass. Injury to beans, beets, red clover, cowpeas, potatoes, chrysanthemums, morning-glories, eggplant, cabbages, and pumpkins also occurred at that time.

In 1907 F. H. Chittenden (10, p. 118) reported that the insect "lives in great numbers on the leaves, puncturing them so as to cause the death of the tissues in small irregular white patches. In its short-winged form it resembles the black flea-beetles, which affect potato, alike in appearance, in the nature of its work, and in its saltatory power. Other food plants include potato, pumpkin, cabbage, ornamental plants, clover, and many weeds."

In 1907 F. M. Webster recorded *H. uhleri* as destructive to alfalfa over small areas at Topeka, Kans.

In the Yearbook of 1908 Dr. Chittenden (11) gives the following account of *H. citri*:

The garden flea-hopper (*Halticus uhleri* Giard) was more or less injurious to cucumbers, squash, and beans in New Jersey; to beans in the District of Columbia, and to lettuce and sweet potato in the trucking region of Norfolk, Va.

C. E. Sanborn (14) found the species destructive to alfalfa in Oklahoma in 1912. During the same year J. J. Davis (13) gives the following account of *Halticus citri*:

This flea-hopper did much damage to smilax in several greenhouses around Chicago in 1908 . . . and just outside of the house the weeds were much infested with it—the latter fact probably accounting for its presence indoors. Early in the spring of 1909 the adults—fully winged males and females as well as the short-winged form—were found abundant in one greenhouse at a date which would preclude any possibility of their having developed out-of-doors that spring; and they did not develop inside the greenhouses from eggs deposited the fall before, as the houses had been examined during the winter and not an active "hopper" found. It was also observed that the individuals became adult in the fall, as cold weather set in. From these observations it appears that the adults hibernate in greenhouses or out-of-doors and become active in the spring, when they deposit their eggs for that season's generation—instead of doing it in the fall before, as has heretofore been supposed.

Following are from the notes of Mr. G. G. Ainslie, of the Bureau of Entomology:

Clemson College, S. C., July 16, 1909: The alfalfa is conspicuously whitened by the adults and larvæ of this bug which have come there from the adjoining peas. The habitats of the insect seem to be the same on alfalfa as peas. The adults are found on both sides of the leaves but mainly the lower, while the larvæ are confined to the lower side.

Nashville, Tenn., September 5, 1910: Found a field of alfalfa badly whitened by the attacks of this species. The plants looked sickly from the work of these bugs.

July 13, 1913, Mr. E. B. Blakeslee of Winchester, Va., reported to Prof. A. L. Quaintance of the Bureau of Entomology the occurrence of enormous numbers of *H. citri* in alfalfa fields, both in the adult and

nymphal stages. Mr. J. R. Stewart, of Gray, Ga., under the date of May 9, 1915, reported severe injury by the garden flea-hopper to a field of alfalfa that had yielded fine crops for two years.

Mr. E. H. Gibson on May 26, 1916, reported it as being injurious to alfalfa at Charleston, Mo.

RECENT INJURIES.

During the year 1915 serious attacks by *Halticus citri* on cereal and forage crops in the South Atlantic States, and especially in Georgia,



FIG. 2.—Alfalfa showing the effect of injury by the garden flea-hopper on the leaves.

directed the attention of the Bureau of Entomology to the need of investigational work with respect to this insect. The late Prof. F. M. Webster, entomologist in charge of cereal and forage insect investigations, immediately instituted researches for the purpose of determining suitable control measures.

The writer began his investigations at Gray, Ga., May 26, 1915. In walking through the alfalfa fields at this place infestation by the garden flea-hopper was found exceedingly abundant, the insect being present in all stages of its life cycle; the distribution of the pest in

each field was found to be quite uniform excepting along the fences, where the plants were most seriously affected, leaves being discolored and dropping off, and the plants dying in frequent instances.

It was observed that the injury caused to alfalfa by *Halticus citri* very closely resembled that of the red spider (*Tetranychus bimaculatus* Harv.).

All the cereal and forage and truck crops, wild mulberry trees, peach trees, and a large number of weeds, including the briar and



FIG. 3.—At the right, normal healthy leaves of red clover. At the center and left, leaves seriously affected by the garden flea-hopper.

species of the mint family, were found infested with this insect. More noticeable damage, however, was shown by alfalfa, cowpeas, and clover than by other growing crops.

DAMAGE TO ALFALFA.

The injury which is inflicted on alfalfa and other plants is caused by both adults and nymphs. Damage is done by means of their sharp pointed mouth-parts which are inserted into the plant tissues. The short chitinized beak is thrust through the surface of the leaf or its

petiole and sap is extracted, giving the leaves a bleached appearance and often killing them. In extreme cases the stems of the plants are attacked in like manner. The greatest amount of damage results from the loss of plant sap or juices. The leaves die and in many instances drop from the stems and cause the infested plants to appear as bunches of stubble. (See figs. 2 to 6.)

The loss to the crop has been estimated by the writer as high as 50 to 60 per cent in several severely infested fields where the alfalfa had been cut and the cured hay removed. The damage is quite noticeable



FIG. 4.—White clover showing the effect of injury on the leaves by the garden flea-hopper.

in the field, since the plants have not the green color and freshness characteristic of plants that are uninjured, and have become fibrous, contrasting with other plants of luxuriant growth and thrifty condition. The extraction of the plant juices checks the growth of the plant, causing it to shrivel up and in a number of instances to die. After the crop has been cut and the hay removed from the field an inspection of the alfalfa field shows that a large number of the leaves have fallen from the plants and been left lying on the ground, causing a loss of much of the food

value of the hay. This is due in large measure to the injury resulting from the feeding of the garden flea-hopper upon the petioles, leaves, and tender stems.

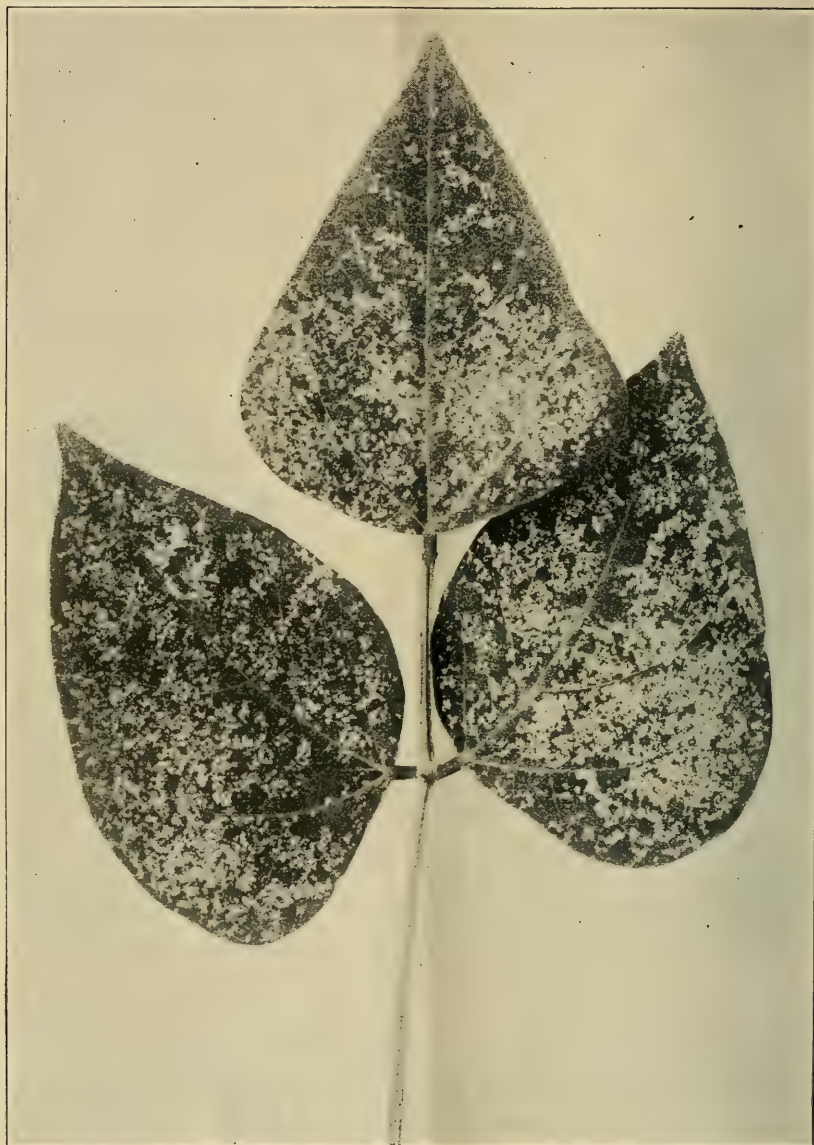


FIG. 5.—Cowpeas showing the effect of injury by the garden flea-hopper on the leaves.

HOST PLANTS.

Throughout the South Atlantic States the species was found prevalent on alfalfa, the clovers, cowpeas, and some of the common

weeds. All common garden truck was also found to be among the favorite host plants with the possible exception of the red pepper plant which showed very slight attack or injury. It was found on

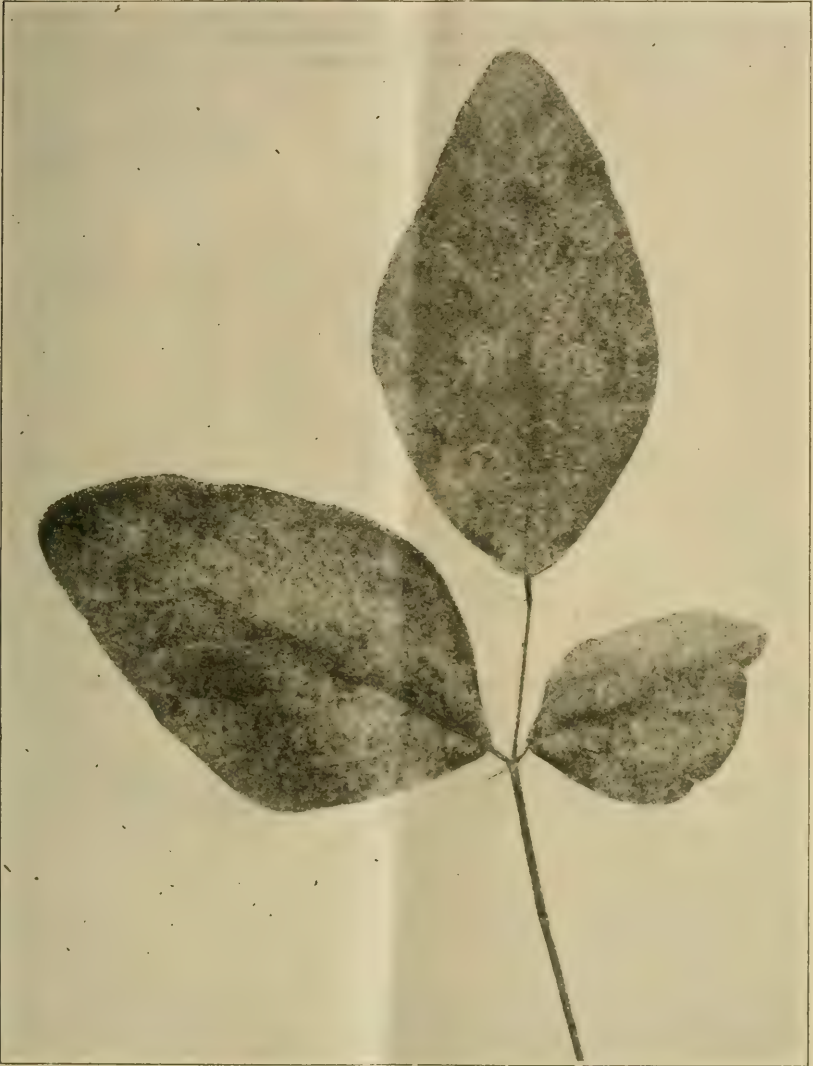


FIG. 6.—Beggar-weed (*Meibomia tortuosa*) showing the effect of feeding of the garden flea-hopper upon the leaves.

plants in greenhouses the year round, and on the out-of-door flowering plants it was especially noticeable in the early spring and late fall, although also common throughout the summer.

Tables I, II, and III were prepared after a close examination of the most seriously infested host plants collected from the fields in which outbreaks occurred, and show that alfalfa is most frequented by *Halticus citri* for egg laying.

TABLE I.—*Infestation in alfalfa by Halticus citri, showing the number of eggs in each leaf and where deposited.*

Leaf No.	Eggs deposited in upper surface.	Eggs deposited in lower surface.	Total number of eggs deposited.	Leaf No.	Eggs deposited in upper surface.	Eggs deposited in lower surface.	Total number of eggs deposited.
1.....	3	1	4	27.....	3	0	3
2.....	11	0	11	28.....	2	0	2
3.....	12	7	19	29.....	3	0	3
4.....	5	1	6	30.....	16	2	18
5.....	2	1	3	31.....	30	0	30
6.....	1	1	2	32.....	53	0	53
7.....	7	0	7	33.....	10	7	17
8.....	3	0	3	34.....	31	0	31
9.....	15	0	15	35.....	6	0	6
10.....	4	0	4	36.....	23	0	23
11.....	5	0	5	37.....	15	1	16
12.....	1	0	1	38.....	23	15	38
13.....	28	1	29	39.....	2	0	2
14.....	4	0	4	40.....	3	0	3
15.....	5	10	15	41.....	5	0	5
16.....	0	0	0	42.....	2	1	3
17.....	1	0	1	43.....	2	0	2
18.....	2	5	7	44.....	3	0	3
19.....	10	1	11	45.....	5	0	5
20.....	2	0	2	46.....	3	0	3
21.....	12	4	14	47.....	7	1	8
22.....	2	2	4	48.....	1	1	2
23.....	1	0	1	49.....	20	1	21
24.....	6	1	7	50.....	9	0	9
25.....	8	1	9				
26.....	1	0	1	Total..	428	65	493

TABLE II.—*Infestation in clover by Halticus citri, showing the number of eggs in leaf and where deposited.*

Leaf No.	Eggs deposited in upper surface.	Eggs deposited in lower surface.	Total number of eggs deposited.	Leaf No.	Eggs deposited in upper surface.	Eggs deposited in lower surface.	Total number of eggs deposited.
1.....	2	0	2	27.....	0	0	0
2.....	0	0	0	28.....	1	0	1
3.....	3	1	4	29.....	8	6	14
4.....	7	3	10	30.....	5	1	6
5.....	11	1	12	31.....	14	0	14
6.....	9	0	9	32.....	9	3	12
7.....	14	2	16	33.....	2	4	6
8.....	2	0	2	34.....	13	2	15
9.....	0	0	0	35.....	1	0	1
10.....	10	0	10	36.....	0	3	3
11.....	1	0	1	37.....	0	1	1
12.....	4	0	4	38.....	6	0	6
13.....	0	0	0	39.....	4	0	4
14.....	1	1	2	40.....	2	4	6
15.....	3	0	3	41.....	1	0	1
16.....	5	0	5	42.....	10	1	11
17.....	8	2	10	43.....	0	0	0
18.....	0	1	1	44.....	1	0	1
19.....	2	0	2	45.....	5	0	5
20.....	4	0	4	46.....	2	0	2
21.....	1	0	1	47.....	7	1	8
22.....	6	2	8	48.....	4	0	4
23.....	0	0	0	49.....	9	2	11
24.....	1	0	1	50.....	3	0	3
25.....	10	3	13				
26.....	11	1	12	Total..	222	45	267

TABLE III.—Infestation in cowpeas by *Halticus citri*, showing the number of eggs in the leaf and where deposited.

Leaf No.	Eggs deposited in upper surface.	Eggs deposited in lower surface.	Total number of eggs deposited.	Leaf No.	Eggs deposited in upper surface.	Eggs deposited in lower surface.	Total number of eggs deposited.
1.....	4	1	5	27.....	9	0	9
2.....	0	0	0	28.....	3	6	9
3.....	1	0	1	29.....	1	0	1
4.....	2	0	2	30.....	2	0	2
5.....	0	0	0	31.....	0	0	0
6.....	6	0	6	32.....	6	0	6
7.....	1	6	7	33.....	1	0	1
8.....	0	0	0	34.....	4	1	5
9.....	6	2	8	35.....	1	0	1
10.....	9	0	9	36.....	11	2	13
11.....	10	2	12	37.....	0	3	3
12.....	4	0	4	38.....	2	0	2
13.....	1	0	1	39.....	7	0	7
14.....	2	0	2	40.....	3	1	4
15.....	5	0	5	41.....	2	0	2
16.....	0	0	0	42.....	0	0	0
17.....	8	1	9	43.....	1	0	1
18.....	1	4	5	44.....	0	0	0
19.....	0	8	8	45.....	4	1	5
20.....	6	1	7	46.....	2	0	2
21.....	4	0	4	47.....	1	0	1
22.....	6	0	6	48.....	3	0	3
23.....	1	0	1	49.....	2	1	2
24.....	12	2	14	50.....	1	0	1
25.....	7	0	7				
26.....	2	4	6				
				Total...	164	46	210

In the field observations and laboratory studies it was found that *Halticus citri* prevails on a wide range of species of host plants. The following is a list of the host plants, as noted by the writer, together with those recorded in the literature:

Alfalfa (*Medicago sativa*), red clover (*Trifolium pratense*), cowpeas (*Vigna sinensis*), ragweed (*Ambrosia artemisiaefolia*), hollyhock (*Althaea rosea*), ground cherry (*Physalis pubescens*), sorghum (*Andropogon sorghum*), prickly lettuce (*Lactuca scariola*), burdock (*Arctium lappa*), thistle (*Cnicus arvensis*), crab-grass (*Syntherisma sanguinale*), Kentucky bluegrass (*Poa pratensis*), oats (*Avena sativa*), rye (*Secale cereale*), wheat (*Triticum vulgare*), corn (*Zea mays*), rape (*Brassica napus*), barley (*Hordeum vulgare*), Jerusalem artichoke (*Helianthus tuberosus*), Johnson grass (*Andropogon halepensis*), celery (*Apium graveolens*), wild mulberry (*Morus rubra*), bur clover (*Medicago arabica*), sweet clover (*Melilotus alba*), wild morning-glory (*Convolvulus arvensis*), hackberry (*Celtis occidentalis*), cocklebur (*Xanthium* sp.), eggplant (*Solanum melongena*), Irish potato (*Solanum tuberosum*), sweet potato (*Ipomoea batatas*), peach (*Amygdalus persica*), cucumber (*Cucumis* sp.), tomato (*Lycopersicon lycopersicon*), tobacco (*Nicotiana tabacum*), bean (*Phascolus* sp.), May-pops (*Passiflora incarnata*), marigold (*Calendula officinalis*), verbena (*Verbena incisa*), cotton (*Gossypium hirsutum*), beggar-weed (*Meibomia tortuosa*), white clover (*Trifolium carolinianum*).

DESCRIPTION.

ADULT.

On first sight the brachypterous female adult of this species (fig. 7) is likely to be confused with that of a flea-beetle, since both are saltatorial and resemble each other in color and general appearance, even though they represent two different orders.

The male (fig. 8) has the normal form of the Hemiptera, while the brachypterous female may easily be taken for another species. The macropterous female (fig. 9) resembles the male, having long wings but is somewhat larger than the male.

H. H. Knight, of the department of entomology, Cornell University, Ithaca, N. Y., has kindly drafted the following redescription of the adult, from specimens furnished by the writer from Columbia, S. C.

Slightly smaller and less shining than *apterus* L.; in addition to the vestiture of very fine pale pubescence, having on the dorsum deciduous tomentose patches which give silvery to greenish reflections as in *intermedius* Uhler.



FIG. 7.—*Halticus citri*: Brachypterous female. Greatly enlarged.

Pronotum.—Length 0.40 mm., width at base 0.74 mm., collar and calli not apparent; black, moderately shining, the disk having patches of deciduous tomentose pubescence as on the hemelytra. Scutellum, sternum, and pleuræ black, moderately shining.

Hemelytra.—Sides nearly parallel; black, the clavus and corium having patches of deciduous tomentose pubescence, the patches arranged in more or less definite rows; cuneus black, the apex pale yellowish. Membrane pale, tinged with fuscous, one cell apparent but not distinct.

Legs.—Long and slender, the hind femora saltatorial, coxæ black, front and middle femora pale yellow, the hind pair black with the apex pale; tibiæ pale yellow, the hind pair fuscous near the base; tarsi pale yellowish, the tips fuscous, claws black.

Venter.—Black, moderately shining, genital claspers small but distinctive of the species.

FEMALE (MACROPTEROUS).

Length 2.17 mm., width 0.95 mm., very similar to the male but more robust and having the second antennal segment and the femora differently colored.

Head.—Length 0.25 mm., width across eyes 0.57 mm., vertex 0.31 mm.; not differing from the male.

Antennæ.—Segment I, length 0.22 mm., fuscous to blackish, paler at the base; II, 0.98 mm., pale with the basal and apical one-fourth blackish; III, 0.77 mm., fuscous, pale toward the base; IV, 0.48 mm., fuscous.

MALE (MACROPTEROUS).

Length 2.1 mm. (1.9 to 2.1 mm.), width 0.74 mm.; slightly smaller and more slender than the female.

Head.—Length 0.22 mm., width across eyes 0.56 mm., vertex 0.31 mm. Nearly vertical, front prominent, more or less sulcate at the base of the tylus; black, shining; carina formed by a sharp basal margin of the head. Rostrium reaching to the posterior margin of the middle coxæ; first two segments black, the third and all but the apex of the fourth pale.

Antennæ.—Long and slender, reaching beyond the tip of the membrane; segment I, length 0.25 mm., pale, sometimes darkened at the apex, two or three prominent bristles just before the tip; II, 1.05 mm., black, linear, and slender; III, 0.83 mm., fuscous to black, usually pale at the base, more slender than the second; IV, 0.54 mm., fuscous, very slender.

EGG.

Fig. 10.

Egg cylindrical, roundly pointed at caudal end, broadly truncate at cephalic end. One side decidedly convex, opposite side slightly concave. Chorion smooth, lustrous, pearly white, semitransparent, free from sculpture, except surface of truncate end, which is roughly shagreened. Truncate end apparently with a collar, below which the egg is slightly constricted, end ellipsoidal in outline. Dimensions, long diameter, 0.21 mm., short diameter, 0.10 mm. Length of egg, outer angle 0.71 mm., length of inner angle, 0.56 mm. Diameter at widest point, 0.20 mm.

NYMPH.

Figs. 11-15.

The nymph resembles the adult in general outline and structure but differs in color, and has, in the place of wings such as the adults



FIG. 10.—*Halticus citri*: a, Eggs in alfalfa leaf; b, egg greatly enlarged.

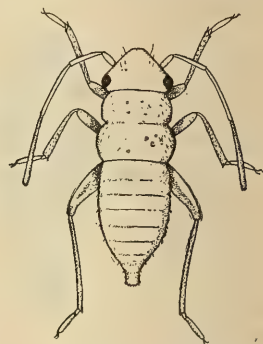


FIG. 11.—*Halticus citri*: First nymphal instar. Greatly enlarged.

have, dark-colored wing pads, these being most pronounced in the fifth stage. In the first nymphal instar the body is less robust and of a pale clay-yellow color at hatching which turns to pale green after feeding. During the period from the second to the fifth instars, inclusive, the thorax and abdomen increase in size laterally. The body gradually becomes more robust, and at the fifth instar it has assumed almost the shape and form of the adult. The color of the body varies from a light to a dark green.

The period of time consumed in the development of the nymph ranges from 10 to 18 days, or an average of 14 days, as shown in Table V.

FIRST INSTAR.

Fig. 11

Length 0.70 mm., width 0.19 mm. (average of 6 specimens). Number of body joints 13. Segments of abdomen 10. Head, thorax, abdomen, and all appendages pale clay color. Head as wide as body, as long as wide. Eyes lateral and prominent, oval shaped, with hexagonal facet structure, carmine in color. Beak 0.21 mm. long; three joints, dark at apex. Antennae tubular; composed of four joints, first slightly swollen, length 0.08 mm., second 0.15 mm., third 0.20 mm., fourth 0.25 mm.; total length 0.68 mm.

TABLE V.—Number of instars, their length, and length of nymphal life of *Halticus citri* during the months of June, July, August, and October, 1915, at Columbia, S. C.

Date of egg deposit.	Date of hatching of egg.	Date of first molt.	Length of stage I. Days. hours.	Date of second molt.	Length of stage II. Days. hours.	Date of third molt.	Length of stage III. Days. hours.	Date of fourth molt.	Length of stage IV. Days. hours.	Date of fifth molt.	Length of stage V. Days. hours.	Total length of nymphal period.		Mean average temperature.
												Sex.	Period.	
June 18.	June 20, 2 p. m.	June 28, 2 p. m.	2 0	June 29, 2 p. m.	2 0	June 30, 2 p. m.	1 0	July 2, 9 a. m.	1 19	July 7, 8 a. m.	5 0	Male.	Days. hours.	* F.
Do.	do.	June 27, 2 p. m.	2 0	July 1, 9 a. m.	3 19	July 8, 8 a. m.	4 0	July 9, 9 a. m.	1 0	July 15, 9 a. m.	4 0	Female.	11 19	76.6
Do.	do.	June 28, 2 p. m.	2 0	July 1, 2 p. m.	4 0	July 3, 9 a. m.	1 19	do.	6 0	July 10, 2 p. m.	1 5	do.	15 0	77.1
Do.	June 29, 9 a. m.	do.	2 0	July 2, 9 a. m.	2 19	July 12, 9 a. m.	2 0	July 9, 9 a. m.	0 19	July 16, 9 a. m.	3 0	Female.	17 19	78.2
Do.	do.	do.	3 5	July 2, 9 a. m.	2 19	July 5, 9 a. m.	2 0	July 7, 9 a. m.	3 0	July 10, 9 a. m.	3 0	do.	14 0	77.4
Do.	do.	do.	3 5	do.	3 0	do.	2 0	do.	2 0	do.	3 0	Male.	11 0	77.4
Do.	do.	do.	3 5	July 2, 9 a. m.	2 19	July 5, 9 a. m.	2 0	do.	2 0	do.	3 0	Female.	14 0	77.4
Do.	do.	do.	3 5	do.	2 19	July 7, 2 p. m.	3 5	July 7, 2 p. m.	2 0	July 10, 2 p. m.	3 0	Male.	14 5	77.4
Do.	do.	do.	3 5	July 2, 2 a. m.	3 19	do.	3 0	July 8, 2 p. m.	3 0	July 11, 9 a. m.	3 0	Female.	15 0	77.8
Do.	do.	do.	3 5	July 3, 9 a. m.	1 0	July 4, 2 p. m.	1 5	July 7, 9 a. m.	2 0	July 10, 9 a. m.	3 0	do.	14 0	77.4
Do.	do.	do.	3 5	July 1, 2 p. m.	2 0	do.	3 0	July 7, 2 p. m.	3 0	July 11, 9 a. m.	3 19	Male.	15 0	77.8
Do.	do.	do.	3 5	July 2, 9 a. m.	1 19	July 5, 9 a. m.	2 0	July 7, 9 a. m.	3 0	July 10, 9 a. m.	3 0	do.	14 0	77.4
Do.	do.	June 28, 2 p. m.	2 5	June 30, 2 p. m.	2 0	July 2, 2 p. m.	2 0	July 5, 2 p. m.	3 0	do.	4 19	Male.	14 0	77.4
Do.	do.	do.	2 5	do.	2 0	do.	2 0	do.	3 0	do.	4 19	do.	14 0	77.4
Do.	do.	do.	2 5	July 2, 2 p. m.	4 0	July 3, 2 p. m.	1 0	do.	3 0	July 8, 2 p. m.	3 0	Female.	12 5	77.7
Do.	do.	do.	2 5	June 30, 2 p. m.	2 0	July 2, 9 a. m.	1 19	July 8, 9 a. m.	6 0	July 12, 9 a. m.	4 0	do.	16 0	78.1
Do.	do.	do.	2 5	July 1, 2 p. m.	3 0	July 2, 9 a. m.	1 0	July 5, 9 a. m.	2 19	July 9, 9 a. m.	4 0	Male.	13 0	77.2
Do.	do.	June 29, 9 a. m.	2 5	June 30, 2 p. m.	2 0	July 3, 2 p. m.	3 0	July 6, 9 a. m.	2 19	July 11, 9 a. m.	5 0	do.	15 0	77.8
Do.	do.	do.	2 0	do.	2 5	July 2, 2 p. m.	2 0	do.	3 10	July 10, 9 a. m.	4 0	do.	14 0	77.4
Do.	do.	do.	2 0	do.	2 5	July 2, 2 p. m.	3 0	July 5, 9 a. m.	3 0	July 12, 9 a. m.	4 0	do.	16 0	78.1
Do.	do.	June 29, 9 a. m.	3 0	June 30, 2 p. m.	1 19	July 2, 9 a. m.	1 19	July 5, 9 a. m.	3 0	July 9, 9 a. m.	4 0	do.	13 11	77.2
Do.	do.	June 29, 9 a. m.	3 0	July 1, 2 p. m.	2 5	July 5, 9 a. m.	3 19	July 9, 9 a. m.	4 0	July 14, 9 a. m.	5 0	do.	18 0	77.8
Average.			2.77 0		2.68 0		2.27 0		3 0		3.6 0		14.1 0	77.60
July 21.	July 30, 9 a. m.	Aug. 1, 9 a. m.	1 0	Aug. 3, 9 a. m.	2 0	Aug. 5, 9 a. m.	2 0	Aug. 7, 9 a. m.	2 0	Aug. 10, 9 a. m.	3 0	Female.	10 0	79
July 9.	Aug. 7, 9 a. m.	Aug. 10, 9 a. m.	3 0	Aug. 11, 2 p. m.	1 0	Aug. 13, 2 p. m.	2 0	Aug. 15, 9 a. m.	1 19	Aug. 15, 9 a. m.	3 0	do.	19 19	80
Do.	do.	do.	3 0	Aug. 12, 9 a. m.	2 0	do.	3 0	do.	1 19	do.	3 0	do.	11 0	80
Do.	do.	do.	3 0	Aug. 11, 2 p. m.	1 5	do.	2 0	Aug. 14, 2 p. m.	1 0	Aug. 17, 9 a. m.	2 19	Male.	10 0	80
Do.	do.	do.	3 0	Aug. 11, 9 a. m.	1 0	Aug. 13, 9 a. m.	2 0	Aug. 15, 9 a. m.	1 0	Aug. 17, 2 p. m.	2 5	Female.	10 5	80
Do.	do.	do.	3 0	do.	2 0	do.	2 0	do.	2 0	do.	2 0	do.	10 0	80
Do.	do.	Aug. 9, 9 a. m.	2 2	do.	2 0	do.	2 0	do.	2 5	Aug. 17, 2 p. m.	2 0	do.	10 5	80
Do.	do.	do.	2 0	do.	2 0	do.	2 0	do.	2 5	Aug. 18, 9 a. m.	2 19	do.	11 5	80
Do.	do.	Aug. 9, 9 a. m.	2 2	do.	2 0	Aug. 12, 2 p. m.	1 0	Aug. 11, 2 p. m.	2 0	Aug. 17, 9 a. m.	2 0	Female.	10 0	80
Do.	do.	do.	2 0	Aug. 10, 9 a. m.	1 0	Aug. 12, 9 a. m.	2 0	Aug. 14, 9 a. m.	2 0	Aug. 18, 9 a. m.	4 5	Male.	11 5	80
Do.	do.	do.	2 0	Aug. 13, 9 a. m.	3 0	Aug. 15, 9 a. m.	1 0	Aug. 16, 9 a. m.	2 0	Aug. 21, 9 a. m.	4 0	do.	12 0	80
Do.	do.	do.	2 0	Aug. 12, 2 p. m.	1 5	Aug. 14, 9 a. m.	1 19	Aug. 16, 9 a. m.	2 0	Aug. 19, 2 p. m.	3 5	do.	10 5	80
Do.	do.	do.	2 0	Aug. 13, 9 a. m.	2 0	Aug. 15, 2 p. m.	2 0	Aug. 17, 9 a. m.	1 19	Aug. 21, 9 a. m.	4 0	do.	10 0	80
Do.	do.	do.	2 0	Aug. 13, 9 a. m.	2 0	Aug. 15, 2 p. m.	2 0	Aug. 17, 9 a. m.	1 19	Aug. 21, 9 a. m.	4 0	do.	10 0	80
Do.	do.	do.	2 0	Aug. 13, 9 a. m.	2 0	Aug. 14, 4 p. m.	1 7	Aug. 16, 2 p. m.	1 22	Aug. 20, 9 a. m.	3 19	do.	11 0	80
Do.	do.	do.	2 0	Aug. 15, 2 p. m.	2 5	Aug. 17, 2 p. m.	3 0	Aug. 19, 4 p. m.	1 2	Aug. 23, 9 a. m.	3 17	Female.	13 0	80
Do.	do.	do.	3 0	do.	2 5	Aug. 17, 9 a. m.	1 19	Aug. 20, 9 a. m.	3 0	do.	3 0	Male.	13 0	80
Do.	do.	do.	2 5	do.	2 5	do.	1 19	Aug. 19, 2 p. m.	2 5	Aug. 22, 2 p. m.	3 0	Female.	11 5	80
Do.	do.	do.	2 5	do.	2 5	do.	2 5	Aug. 21, 9 a. m.	2 5	Aug. 24, 9 a. m.	3 0	do.	12 0	80
Do.	do.	do.	2 5	do.	2 5	Aug. 17, 9 a. m.	1 19	Aug. 19, 2 p. m.	2 5	Aug. 22, 2 p. m.	3 0	do.	11 5	80
Do.	do.	do.	2 5	do.	2 5	Aug. 23, 9 a. m.	1 17	Aug. 25, 9 a. m.	3 0	do.	3 0	Male.	11 0	80
Do.	do.	do.	1 5	Aug. 19, 4 p. m.	3 0	Aug. 22, 2 p. m.	3 5	do.	2 1	do.	3 0	do.	11 0	80
Do.	do.	do.	2 19	Aug. 23, 2 p. m.	1 5	Aug. 24, 2 p. m.	1 0	Aug. 26, 2 p. m.	2 0	Aug. 31, 9 a. m.	4 19	do.	11 19	80
Do.	do.	do.	5 5	do.	2 0	Aug. 26, 2 p. m.	2 0	Aug. 29, 9 a. m.	2 19	do.	3 0	Female.	12 0	80
Average.			2.25+0		1.79+0		2 0		2 0		3.01 0		12 0	79.95
Oct 2.	Oct 11, 9 a. m.	Oct 13, 2 p. m.	2 5	Oct 16, 9 a. m.	2 19	Oct 19, 9 a. m.	3 0	Oct 22, 9 a. m.	3 0	Oct 27, 9 a. m.	5 0	Male.	16 0	71
Oct 2.	do.	do.	2 0	do.	2 19	Oct 19, 9 a. m.	2 19	Oct 21, 9 a. m.	3 0	Oct 25, 10 a. m.	2 0	Female.	12 1	80
Oct 2.	do.	do.	5 0	Oct 17, 2 p. m.	1 5	Oct 19, 9 a. m.	1 19	Oct 22, 9 a. m.	3 0	Oct 27, 9 a. m.	5 0	Male.	16 0	71
Oct 2.	do.	do.	2 5	Oct 20, 9 a. m.	3 19	do.	2 0	do.	3 0	do.	5 0	do.	16 0	71
Oct 4.	do.	do.	2 5	Oct 16, 9 a. m.	2 19	Oct 19, 9 a. m.	3 0	Oct 23, 9 a. m.	4 0	Oct 28, 9 a. m.	5 0	Female.	17 0	71
Average.			2.6 0		2.6 0		2.2 0		3.2 0		4.8 0		15.8 0	71

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Body: Widest at the head and thorax, caudal end bluntly pointed when viewed from the dorsum.

Legs: Femur covered with long sparse hairs; tibia covered with numerous short, stiff, appressed hairs; tarsi covered with numerous short, stiff hairs, end of tarsi having two small hooks.

SECOND INSTAR.

Fig. 12.

Length 0.81 mm., width 0.27 mm. at widest part of the body. Thorax and abdomen pale green, appendages clay color. Eyes lateral and prominent, oval shaped, with hexagonal facet structure, color carmine. Beak 0.32 mm.; of three joints, dark at apex, sucking tube brownish. Antennæ tubular, of four joints, the first slightly swollen; amber colored, pubescent, hairs somewhat appressed; first joint 0.08 mm. in length, second 0.22 mm., third 0.25 mm., fourth 0.24 mm., total 0.79 mm.

Body: Each segment with sparse, short, stiff hairs. Body widest at fifth abdominal segment, tapering bluntly at posterior extremity.

Legs: Amber colored, femur covered with long, sparse hairs; tibia bearing short, stiff, appressed hairs; tarsi bearing numerous short, stiff hairs, end of tarsi having two small hooks.

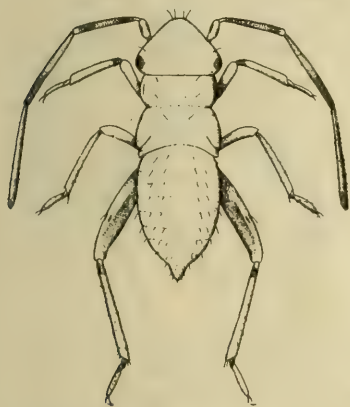


FIG. 12.—*Halticus citri*: Second nymphal instar. Greatly enlarged.

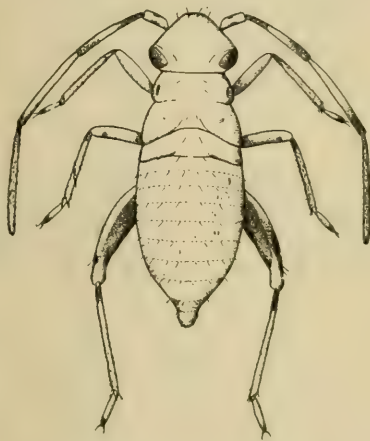


FIG. 13.—*Halticus citri*: Third nymphal instar. Greatly enlarged.

THIRD INSTAR.

Fig. 13.

Length 1.03 mm., greatest body width 0.32 mm., width of head at widest point 0.29 mm.

Head brownish, thorax and abdomen varying in color from pale to dark green, appendages amber colored. Eyes lateral and prominent, oval shaped, with hexagonal facet structure, color carmine. Beak 0.38 mm. long, three-jointed, amber colored, terminal joints dark at apex. Sucking tube brownish. Antennæ tubular, four-jointed, amber colored, pubescent, hairs somewhat appressed; first joint 0.29 mm. in length, second 0.31 mm., third 0.22 mm., fourth 0.13 mm., total length 0.95 mm.

Body: Number of joints as in preceding instar. On dorsum of each joint one short, stiff hair and on lateral side of dorsum one stiff hair. Color pale green. Body widest at fifth abdominal segment, tapering bluntly at posterior extremity.

Legs: Femur covered with long, sparse hairs; tibia bearing short, stiff, appressed hairs, tarsus bearing numerous short, stiff hairs, end of tarsi having two small hooks.

FOURTH INSTAR.

Fig. 14.

Length 1.21 mm., width of body at widest point 0.44 mm., width of head at widest point 0.32 mm. Thorax and abdomen light to dark green, head brownish. Eyes lateral and prominent, oval shaped, with hexagonal facet structure, color carmine. Beak 0.56 mm. long, of three joints, terminal joints dark at apex, sucking tube dark brown. Antennæ tubular, of four joints, the first slightly swollen; amber colored, pubescent, hairs somewhat appressed; first joint 0.15 mm. in length, second 0.38 mm., third 0.42 mm., fourth 0.40 mm., total 1.35 mm.

Body: Number of joints as in preceding instar. On dorsum of each joint are short, sparse, stiff hairs and on the side one short, stiff hair. Body light to dark green, wider than head at widest point, and tapering bluntly at posterior end.

Legs: Straw colored, femur covered with long, sparse hairs; tibia covered with numerous short, stiff, appressed hairs; tarsus bearing numerous short, stiff hairs.

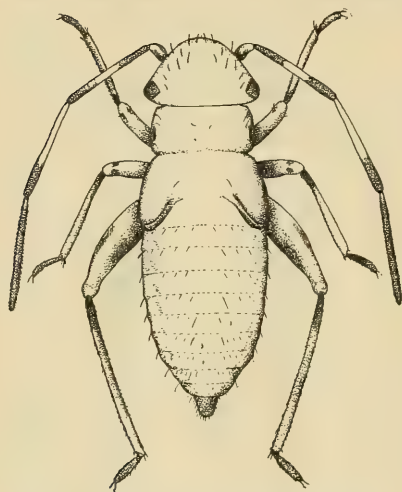


FIG. 14.—*Halticus citri*: Fourth nymphal instar.
Greatly enlarged.



FIG. 15.—*Halticus citri*: Fifth nymphal instar.
Greatly enlarged.

FIFTH INSTAR.

Fig. 15.

Length 2 mm., width 0.98 mm. at widest point two-thirds of the way back from anterior end, height or depth of head 0.40 mm., widest point of head over the eyes 0.51 mm. Color of head brownish, of thorax and abdomen pale to dark green. Eyes lateral and prominent, oval shaped, with hexagonal facet structure, color carmine. Beak 0.95 mm. long, of three joints, terminal joints dark at apex, sucking tube dark brown. Antennæ tubular, of four joints, amber colored, pubescent, more densely at apex, hairs somewhat appressed; first joint 0.19 mm. in length, slightly swollen; second 0.64 mm., tubular, slightly enlarged, and brown; third 0.64 mm., tubular, slender, pale; fourth 0.56 mm., tubular, slender, tapering acutely; total length 2.03 mm.

Body: Abdomen with each joint bearing a short, stiff hair. Body dark green with dark wing pads, wider than head at widest point and tapering bluntly at posterior end.

Legs: Femur bearing long, stiff hairs; tibia bearing numerous short, stiff, appressed hairs; tarsus bearing numerous short, stiff hairs.

LIFE HISTORY AND HABITS.

Difficulty was experienced in securing life-history records during the months of June, July, and August, because of excessive heat. Much patience was needed to bring the adults through the months of January and February, the natural hibernating period. To have the specimens under close observation it was necessary to confine them under more or less artificial conditions. The death rate under these conditions was very high. The combined lengths of the egg, nymphal, and adult stages under conditions at Columbia, S. C., varied with the temperature, being from 58 to 94 days, with an average of 76 days for all conditions.

MATING.

Mating usually takes place soon after the individual reaches maturity. In the series of experiments conducted by the author it took place from 5 minutes to 2 hours and 30 minutes after the last instar matured, usually occurring in the daytime. The time covered in the process of mating as recorded in a series of six experiments ranged from 30 minutes to 1 hour and 35 minutes. After mating, the individuals in each case were observed to move in opposite directions and seek suitable places for feeding.

The brachypterous females are much more abundant throughout the year and were used in nearly all of the life-history experiments. The macropterous female, however, which is very rare, was found to be fertile and to deposit fertile eggs as does the brachypterous form.

OVIPOSITION.

During the spring, summer, and fall, oviposition begins about 4 days after mating according to Tables VI and VII, and was observed to take place principally during the night or early morning (see Table VII).

Individuals of *Halticus citri* almost invariably oviposit on those portions of the plant where previously they have been feeding, the leaves usually being selected with a preference for the upper side (see Tables I, II, and III). In some instances, however, during the late fall and winter in cage experiments (see fig. 16) it was observed that oviposition took place in the stem of the plant and also in the cork which constitutes the bottom of the cages.

TABLE VI.—*Incubation records of eggs obtained from one female of the garden flea-hopper, Columbia, S. C., 1915*
Cage 15-631.

Deposited—		Hatched—		Incubation period.	Deposited—		Hatched—		Incubation period.
Date.	Number of eggs.	Date.	Number of eggs.		Date.	Number of eggs.	Date.	Number of eggs.	
July 28	4	Aug. 5	All.	Days.	Aug. 17	0			Days.
29	2	do.	All.	8	18	0			
30	2	do.	All.	7	19	0			
31	6	Aug. 8	All.	6	20	0			
Aug. 1	4	Aug. 11	All.	8	21	0			
2	7	do.	All.	10	22	0			
3	2	Aug. 9	All.	9	23	3	Sept. 2	All.	10
4	4	Aug. 14	All.	6+	24	0			
5	2	Aug. 11	All.	10—	25	1	Sept. 2	All.	7
6	1	Aug. 14	All.	6+	26	0			
7	0			8	27	0			
8	0				28	1 ♀	Sept. 5	All.	8
9	10 ♂				29	0			
10	4	Aug. 19	All.	9	30	0			
11	0				31	0			
12	0				Sept. 1	10 ♂			
13	0								
14	0				Total.....	43			
15	0				Average incubation				8
16	0								

¹ Dead.

General average of 1.34 per day for 32-day period.

TABLE VII.—*Daily and total production of eggs deposited by one female of H. citri, time of hatching, and length of incubation period, Columbia, S. C., 1916.*
Cage 15-1080.

Deposited—				Hatched—		Incubation period.
Date.	Number of eggs.			Date.	Number of eggs.	
	Day.	Night.	Total.			
Sept. 4	1		1	Sept. 14	All.	Days. 10
5		1	1	Sept. 15	All.	10
6		6	6	do.	All.	8
7		3	3	Sept. 14	All.	8
8		1	1	Sept. 16	All.	8
9	3	2	5	Sept. 18	All.	9
10		4	4	do.	All.	8
11	7	2	9	Sept. 20	All.	9
12		3	3	do.	All.	9
13	9	3	12	Sept. 22	All.	9
14	4		4			
15	6	2	8	Sept. 24	All.	9
16	4	1	5	Sept. 25	All.	9
17	4	6	10	Sept. 26	All.	9
18		1	1	Sept. 27	All.	9
19		2	2	Sept. 28	All.	9
20	3	2	5	Sept. 29	All.	9
21		1	1	do.	All.	8
22		4	4	Sept. 30	All.	9
23		1	1	Oct. 1	All.	7
24		1	1	Oct. 2	All.	0
25	0	0	0		0	0
26	3	3	6	Oct. 5	All.	10
27	3	3	6	Oct. 6	All.	10
28		2	2	Oct. 13	0	
29		3	3	Oct. 9	All.	10
30		3	3	Oct. 10	All.	10
Oct. 1	0	0	0			
2		2	2	Oct. 10	All.	9
3	2		2	Oct. 11	All.	9
4		2	2	Oct. 12	All.	8
5	2		2	Oct. 14	All.	8
6	2		2	do.	All.	8
7	0	0	0			
8		1	1	Oct. 15	All.	8
9		2	2	Oct. 17	All.	8
Nov. 3	♂	Dead.				
Total	53	67	120			
Average						8.04

The female assumes the usual feeding position in which the body is parallel with the surface of the leaf. Apparently after a desirable place is located with the proboscis a puncture is made; the curved or swordlike ovipositor is then advanced to the puncture made by the proboscis immediately after the removal of the proboscis; the ovipositor penetrates the puncture to its full length, and an egg is deposited in the cavity. After the ovipositor is withdrawn a large drop of clear fluid exudes from it, covering the exposed truncate end of the egg.

The process of oviposition requires about 15 to 20 seconds, only one egg being placed in each hole.

EFFECT OF TEMPERATURE ON OVIPOSITION.

It was found that oviposition ceased when the temperature fell below 70° F., and there were no records of oviposition at temperatures above 90° F. In a number of cages (fig. 16) each containing two male and one female flea-hoppers were placed in a well-ventilated basement room of the laboratory, the temperature of which ranged between 75° and 90° F., most of the eggs were deposited in the daytime when a temperature of about 80° F. was reached, which usually occurred in the early morning.

EGG STAGE AND PROCESS OF HATCHING.

Several days before hatching the egg changes from its original pearly white to a pale clay-yellow color, this change being evidence of its fertility. The color of the egg resembles that of the nymph at emergence. The shape and position of the nymph, including the segments of the abdomen, the thorax, the head, the appendages, and the carmine-colored eyes, are distinguishable under a lens. In the egg the nymph is found with its head at the truncate end a short time before hatching, the covering of this end being broken at the edge or through the middle, and opening, in most cases, like a trap-door. The head appears through the opening followed by the thorax and abdomen. The body moves backward and forward in an effort to disengage the appendages from the chorion. The appendages are all laid snugly against the ventral side of the body. The proboscis is the first appendage to be released, followed by the prothoracic and mesothoracic legs. These are then utilized to free the antennæ and metathoracic legs. The entire process requires about one hour.

The egg is slightly swollen before hatching. Following the emergence of the nymph the eggshell collapses and is semitransparent with red pentagonal to polygonal markings. The body and legs of the freshly emerged nymph are pale clay-yellow color, the antennæ straw color, and the eyes carmine. The egg period was found to range from a minimum of 6 days to a maximum of 16 days in the experiments carried out, with an average incubation period of 11 days.

NUMBER AND LENGTH OF INSTARS.

There are five instars. The length of the instars as well as the total length of the nymphal life is slightly variable, as may be noted by reference to Table V. What slight variations there were in the length of these instars may have been due, in large measure, to differences of temperature and food supply.

The intervals between each two instars gradually increases as maturity is reached. There was found to be no relation between the length of the periods and the sex of the individual.

LENGTH OF LIFE OF THE ADULT.

Adults of *Halticus citri* lived for from 9 to 94 days in the rearing experiments, as is shown in Table VIII. The sexual development was found to be complete as soon as they became adults. The females are shown to have lived longer than the males.

TABLE VIII.—*Length of life of adults of Halticus citri.*

No.	Male.			Female.		
	Emerged.	Died.	Days.	Emerged.	Died.	Days.
1.....	July 10	Aug. 9	30	July 13	Aug. 29	42
2.....	July 13	Aug. 26	44	do.....	Aug. 10	28
3.....	July 10	July 19	9	July 15	Aug. 31	47
4.....	do.....	do.....	9	July 12	Aug. 6	25
5.....	July 13	July 26	13	Aug. 15	Sept. 10	26
6.....	Aug. 17	Aug. 30	13	Aug. 17	Sept. 2	16
7.....	Aug. 18	Sept. 10	23	Aug. 31	Nov. 3	64
8.....	Oct. 27	Dec. 22	26	Oct. 27	Jan. 13	78
9.....	do.....	Jan. 29	94	Oct. 28	Jan. 16	70
	Av.....		29.3			44

HIBERNATION.

In experiments carried out by the writer, the last remaining individuals of the adults which had emerged on October 27, 1915, died on January 29, 1916. Other adults of both sexes issued December 18, 1915, and hibernated until March 14, 1916, when they became active again. Eggs were found in the cage on this date. First-stage nymphs were discovered on April 2, 1916.

The garden flea-hopper is found in greatest abundance during August and September, and gradually decreases in number as winter approaches. In the latitude of Columbia, S. C., mortality is greatest in December, very small numbers being found after this date. Many of the adults apparently are killed by the cold weather, and the remainder seek winter protection under the thickest bunches of their favorite host plants, along fences and other well-protected places, where they continue to winter until the plants become green again in the spring, and then deposit eggs before perishing.

SPRING APPEARANCE AND NUMBER OF GENERATIONS.

The adults of the garden flea-hopper in the latitude of Columbia, S. C., usually appear about the middle of March. Much depends upon the season, however, and they have been found soon after the host plants become green and spring is well in evidence. The adults appeared and deposited eggs as early as March 14, 1915, in the field experiments at Columbia, which was the earliest date recorded of the discovery of eggs in the outdoor experiments. Eggs have been secured in the outdoor cages throughout the year, beginning with the middle of March and continuing until the last of November. From five to six generations were reared at the Columbia laboratory. The length of life of each individual is determined largely by the length of life of the adult stage, this being the longest period of the life cycle.

The first generation was found to extend from March 14, 1915, when fertile eggs were first deposited, to May 15, 1915; the second generation extended from May 15 to July 12, 1915; the third from July 12 to September 11; the fourth from September 11 to November 18, and the fifth from November 18, 1915, to February 10, 1916.

FEEDING HABITS.

In almost every instance noted the youngest plants are attacked in preference to the older and more vigorous growths; and when the insects start feeding on a plant they apparently continue until all the sap is extracted, giving the plant a bleached appearance. During the warm seasons the tendency is to feed at the top of the plants, but during cool days and seasons they feed rather at the bases of the plants. It has been noticed that during warm days the individuals seem to show no particular inclination for protection from the sun by seeking the shady side of the leaf. When they are disturbed, however, they immediately seek a place of concealment on the plant or hop to the ground in quest of protection.

In feeding on the host plant, the individual places itself in a position parallel to the surface of the leaf, preferably on the upper surface, with its legs resting on the surface. Then the proboscis is swung down from the ventral side of the body to a perpendicular position and the apex is thrust into the epidermis of the leaf at a point midway between the prothoracic legs, the proboscis is hinged at the second articulation, the head and thorax being bent slightly downward to allow the first and third articulations to meet, the sucking tube remains straight as the open sheaths of the second and third segments leave the sucking tube, and a slight pressure is placed on the apex of the proboscis. A mechanical procedure ensues similar to the pumping process, in which the head and thorax move slightly upward and downward, not sufficiently, however, to straighten the

second and third joints of the proboscis. Probably in this pumping procedure the food is taken into the body through the proboscis. After continuing this process for several minutes at a time the proboscis is straightened and drawn from the tissue of the leaf and swung to its natural position on the ventral surface of the body for a short time; then it is again swung down and cleansed by a stroking process with the forelegs which clasp the proboscis between the tarsal joints. After gradually sliding the proboscis through them the insect starts feeding again.

This habit has been noted alike in all ages of the nymph and adults, both males and females.

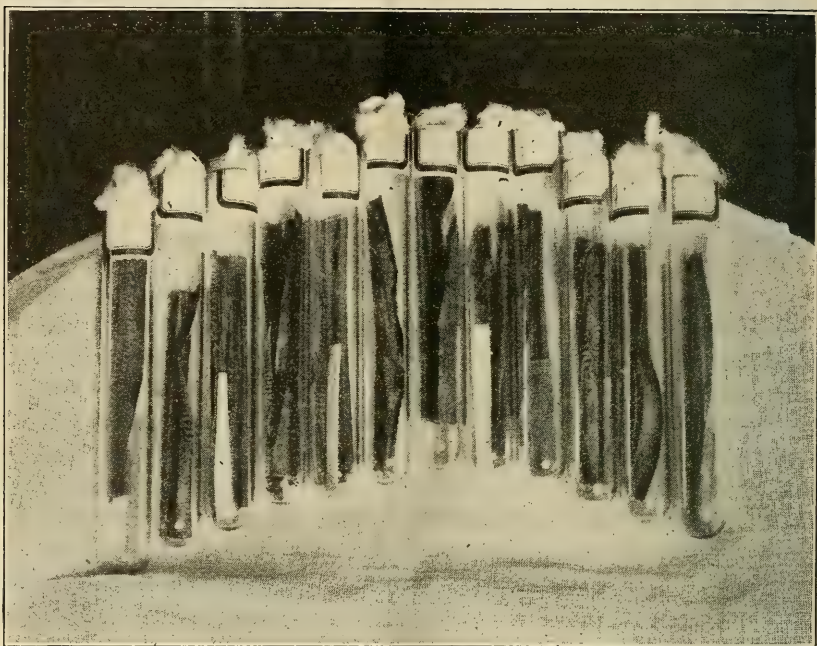


FIG. 16.—Type of cage used in conducting molting experiments with the garden flea-hopper.

PROTECTIVE HABITS.

Both the males and females are saltatorial, as the metathoracic legs are much longer and stronger than the others. The male is found to be decidedly more active than the brachypterous female, a fact probably due to the possession, in addition, of true wings. The adult individuals generally are active and strong as runners and hoppers. When they are only slightly disturbed they hasten immediately for concealment to the opposite side of the leaf of the plant. If the approaching object, however, appears with a violent disturbance, the individual will hop many times its own length to the ground or to another plant where immediate protection may be found.

In a number of experiments different individuals were placed on a large horizontal screen within the room, and the distance of jumps made on the screen ranged from three inches to nearly three feet. In the latter instances they seemingly sustained themselves in the air by the aid of their wings.

The nymphs of the first stage are not saltatorial until nearly time for molting; when disturbed, then, they show slight saltatorial tendencies but are usually very quiet even when disturbed, and merely move slowly to another position on the plant out of danger. They feed on the same place sometimes through several instars. The last three or four instars of the nymph have the same habits of locomotion and are as active as the adults.

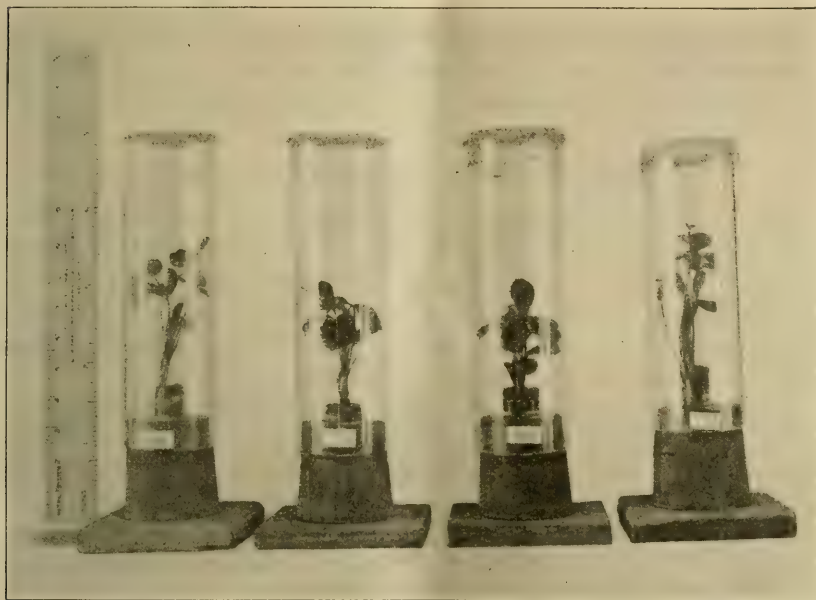


FIG. 17.—Type of cage used in conducting rearing experiments with the garden flea-hopper.

REARING METHODS.

Some difficulty was experienced in acquiring a satisfactory and serviceable rearing cage for the different experiments carried on with this species. Test tubes (fig. 16) were first used as containers for molting experiments and lamp-chimney cages for life-history work. The inaccuracy of the results with these rearing cages necessitated the substitution of one which would be more convenient. The best results were obtained with rearing cages constructed of 1 and 2-inch glass cylinders with cork bases and cloth tops sealed at the edges with glue (fig. 17), each cork base containing 9 by 36 mm. vials with water, and plant food for the insects. The 1-inch cages were attended with greatest success in molting experiments, while the 2-inch cages were used with advantage in life-history work.

NATURAL ENEMIES.

Repeated observations have shown that because of the alertness and saltatorial habits of the nearly grown nymphs and adults of the garden flea-hopper their chances of being attacked by natural enemies are somewhat meager. The nymph in the earlier stages, however, is known to be less active and is frequently attacked by the larva of a small red predacious mite of the family Erythraeidae. The writer also reared a number of egg parasites which have been determined by A. G. Gahan as representing the following species:

Anaphes perdubius Girault.

Tetrastichus sp.

Gonatocerus sp.

Anagrus armatus nigriventris Gir.

Westwoodella americana Ashm.

Abbella subflava Gir.

These species have been reared from the eggs of the garden flea-hopper collected from the alfalfa fields where the outbreaks occurred, and the parasites were believed to have rendered an appreciable amount of good.

REMEDIAL AND PREVENTIVE MEASURES.

Since the garden flea-hopper has an extremely wide range of food plants, though alfalfa is one of its favorite hosts, rotation as a remedy would be out of the question. Clean culture, however, to prevent hibernation in weeds and trash was found to result favorably in controlling the overwintering adults and is the most adequate means thus far devised of reducing the numbers of the pest.

In alfalfa fields where outbreaks of the garden flea-hopper occurred it was observed that timing the removal of the crop so as to destroy the eggs was a vital factor in control. Although a small percentage of the eggs is laid near the ground, the larger proportion is deposited in the delicate leaves and petioles. Some of these leaves containing eggs drop to the ground, it is true, and in numerous cases these eggs hatch; nevertheless, timely cutting will remove the larger number, and this measure is recommended in controlling an outbreak.

DUSTING AND SPRAYING TESTS IN THE FIELD.

A dusting experiment was conducted in one of the alfalfa fields where an outbreak of the garden flea-hopper occurred, the damaged crop being cut and removed from the infested field. An area of 100 square feet was selected and treated thoroughly with a mixture of air-slaked lime and flowers of sulphur in equal proportions. The mixture was thoroughly applied with a hand duster, one application being made in the morning and another at midday. Repeated observations by the writer after the dusting was completed failed to show that the treatment had been effective on any stages of the flea-hopper.

In the same field a plat of similar size was treated with a spray solution composed of potassium sulphid and water at the rate of 1

ounce of the potassium sulphid to 5 gallons of water, a hand sprayer of the compressed-air type being used. The plat was thoroughly sprayed in the morning and also at midday, but even when a stronger solution was employed there was little appreciable benefit from the application.

A spray of kerosene emulsion was next tried on three experimental plats of alfalfa, each having an area of 100 square feet. The alfalfa had been cut and removed a few days before, and the moist weather was causing the new crop to grow rapidly. The stock emulsion was prepared by the following method: One-half pound of laundry soap was dissolved in 1 gallon of hot water; the solution was then removed from the fire, and after 2 gallons of kerosene had been added the material was violently agitated. The table of strengths, as applied in their order on the three plats, follows:

7 per cent strength, $8\frac{1}{2}$ gallons of water added to 1 gallon of stock solution.

10 per cent strength, $5\frac{2}{3}$ gallons of water added to 1 gallon of stock solution.

12 per cent strength, $4\frac{1}{2}$ gallons of water added to 1 gallon of stock solution.

Observations were continued for one day after the spraying experiments were started, and the following results were recorded: The 7 per cent kerosene emulsion was very effective in destroying the garden flea-hopper in all stages; the 10 per cent solution killed practically all the flea-hoppers and did not materially affect the alfalfa; the 12 per cent solution destroyed all of the insects but damaged the alfalfa crop noticeably.

In the campaign against the garden flea-hopper about 12 acres of fields where the most severe outbreaks occurred were sprayed with 10 per cent kerosene emulsion with great success. The solution was applied with an orchard power sprayer having two nozzles, the spray being delivered from the machine at a gauge pressure of 80 pounds and covering a strip 18 feet wide. The machine was driven by a team of mules, and the nozzles were operated by two men at the rear of the machine. An average of 30 gallons was applied to each acre. The cost per gallon of the solution was about 4 cents, thus making the estimated cost per acre \$1.20, nothing being added for labor and machinery, since the farmers had these at their immediate disposal. Since it was estimated that the yield of hay would be a ton per acre under normal conditions, and since spraying with kerosene emulsion as described costs approximately \$1.20 per acre and effects an almost complete saving of the crop, the market price of which has been \$20 per ton, this treatment may be recommended as a satisfactory and economical measure of control.

The only other method of control which effectively overcame the pest was the plowing under of the infested crop, which was done in a number of cases where many of the plants had been killed by the

insect. There are objections to this measure, however, particularly in fields having a good stand. Much labor and expense are required to make a seed bed and to crop the land, and a measure which would involve repetition of these operations would tend to discourage the growing of alfalfa.

SUMMARY.

One of the most striking hemipterous forms of the family Capsidae is the garden flea-hopper, *Halticus citri* Ashm. The male adult has the typical capsid form with long wings, while the female adult differs in appearance, being wingless with a convex robust figure suggesting to the observer a new species. Rarely, female adults are found which resemble the males in general appearance, except that they are more robust and have long wings; this form, however, upon close observation is found to be a trifle larger with a more robust body together with a more perfectly shaped head and thorax, and its genitalia resemble those of the wingless female.

The individuals hop and jump about in the meadow in the manner of leafhoppers. The males are more active than the females, probably because they have functional wings.

In South Carolina and Georgia these insects become abundant in early summer and continue so until late fall, when they gradually disappear, the older individuals dying and the younger seeking hibernation quarters under or at the base of their favorite host plants and in protected places such as fences, terraces, or shrubbery.

Both nymphs and adults suck sap from punctures made in the leaves, petioles, and stems of the plants, causing discoloration, wilting, and, in severe infestation, death.

Leguminous plants appear to constitute its favorite foods and places for breeding, although its range of host plants is extremely wide.

The eggs are deposited in the leaves and petioles of the food plants, usually in places where adults have been feeding.

The incubation period of the egg at Columbia, S. C., covered from 6 to 16 days with an average of 11 days. The five instars of the nymph stage together cover from 10 to 18 days with an average of 14 days. The combined length of nymph and adult stages was 25 days.

In the latitude of South Carolina there are from five to six generations annually. The species was found to hibernate in the adult stage.

The garden flea-hopper is little affected by natural enemies, but changes in weather reduce its numbers during the winter months.

Hibernation and subsequent multiplication are prevented where weeds and plants that remain green late in the fall and resume growth in the spring are cleaned up in the fall and destroyed.

In the case of severe outbreaks of the garden flea-hopper it is advisable to cut and remove the invaded crop and then spray the field with a 10 per cent solution of kerosene emulsion.

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CONTROL OF THE ARGENTINE ANT IN CALIFORNIA CITRUS ORCHARDS.

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INTRODUCTION.

Supposedly introduced into the United States at the close of the nineteenth century the Argentine ant (*Iridomyrmex humilis* Mayr) has since become widely distributed through the more temperate regions, where its complete occupancy, in long-infested localities, and its omnivorous habit bear an important relation to crop production and food storage and rank it as one of the most annoying of household pests. Its discovery in 1908 in cities bordering San Francisco Bay resulted in the initiation of a control campaign under the direction of Prof. C. W. Woodworth, of the University of California, and subsequently led to the development of an arsenical poisoned sirup of considerable merit.

The Argentine ant was recorded in citrus orchards in California almost from the date of its reported presence in the State. It appeared to cause no alarm to orchardists, however, usually remained unnoticed except about the buildings, and where observed was classed

¹ Photographs by senior writer; figure 3 drawn by Miss A. Motter. Mr. Woglum resigned from the Bureau of Entomology September 11, 1920.

merely as "an ant" whose presence was believed in no way detrimental to the trees. The rôle of the Argentine ant as an orchard pest in California was discovered by Mr. J. D. Neuls and the senior writer in 1915 while conducting an investigation of the common mealybug, and its very direct bearing on the control of the mealybug was conclusively proved by an extended series of experiments. This immediately led to an investigation into methods of ant control with which the junior writer became associated in 1917. The great success which attended these experimental efforts led to control demonstrations of considerable proportions in severely ant-infested communities and proved a stimulus to widespread interest in the pest. The demand for relief which followed this awakened interest has already resulted in the treatment of several thousand acres, from a very large part of which the ants have been totally eradicated. This bulletin presents the results of the various remedial methods pursued during the period 1915-1920 and gives full instructions for the control and eradication of ants in the citrus orchards of California.

RELATION OF THE ANT TO THE CITRUS INDUSTRY.

The spread of the Argentine ant in California bears an important relation to citrus growing, a relation certain to become more prominent with wider distribution and long-established infestations. The very severe damage which this pest can sometimes do in citrus orchards has been impressively stated by Newell and Barber² as follows: The bearing qualities of an orchard are severely impaired by the second season of infestation, the crop is almost entirely lost by the third season, and the trees are dying by the fourth year of infestation. This conclusion is based on conditions in Louisiana, and in this respect it should be noted that no systematic effort is made in that State to control citrus scale pests. Such extreme damage has never been observed under California orchard conditions where fumigation and other insecticidal control measures are practiced constantly.

The damage to trees in ant-infested orchards in California does not arise from direct attacks on the blossoms, fruits, and roots, as has been reported from some regions, but is attributable very largely to its so-called symbiotic manner of living with mealybugs, aphids, and various scales, which results in their increase beyond all customary proportions. The constant attendance of the ant protects the mealybugs or scales from their natural enemies and results in their abnormal increase. (See fig. 1.) The degree of infestation is further stimulated and extended through the fact that the ant distributes these injurious insects to other parts of the tree or even

² NEWELL, WILMON, and BARBER, T. C. THE ARGENTINE ANT. U. S. Dept. Agr., Bur. Ent. Bul. 122, p. 192. 1913.

to adjacent trees. The chief damage done by the Argentine ant in California citrus orchards has been through its relation to mealybug infestations, particularly the common mealybug, *Pseudococcus citri* (Risso). Prior to the reported presence of this ant in the Southwest, one species of mealybug was recorded as a serious citrus pest in only three or four limited districts, where it was characterized by sporadic outbreaks which would quickly disappear. In the last decade, which is contemporaneous with the Argentine ant invasion, the severe infestation of the common mealybug has increased many hundred per cent and districts have been invaded from which mealybugs were never before recorded.

In the course of investigations under the direction of the senior writer to establish effective control of the common mealybug, *Pseudococcus citri* (Risso), it was discovered that the Argentine ant not only brings about increased severity of infestation but causes the mealybug to persist year after year. It was furthermore discovered that the common mealybug was attacked by many predatory insects, some of such high efficiency that in ant-free territory they were capable of keeping the mealybug under commercial control except at those infrequent periods normal in the "ups and downs" of



FIG. 1.—Ants attending a group of mealybugs. Their almost constant presence protects the mealybug from its natural enemies.

biologically controlled pests. Demonstrations carried out in several mealybug-ant infested orchards in the San Gabriel Valley during the years 1915 and 1916, in which alternate rows were kept free of ants, proved that trees rid of ants quickly become freed of mealybugs, although on adjacent ant-attended trees the mealybug infestation persists. The results of these demonstrations are verified by the fact that in every experiment performed by the writers during the period of 1915-1920 equally good results have been obtained. The

eradication of the ant in every instance resulted in a reduction of the mealybug infestation to commercial control within a period of from 1 to 3 months. This has been largely due to the increased and unrestricted activity of predatory insects already established.

The citrophilus mealybug, *Pseudococcus gahani* (Green), was first recorded as an orchard pest in 1914 and has never been observed as a severe pest in citrus orchards except in localities infested with the Argentine ant.

The influence of the ant on increased severity of scale pests, while less important than on mealybugs, must be considered. The black scale, *Saissetia oleae* (Bern.), and soft brown scale, *Coccus hesperidum* L., have been observed to become decidedly more numerous on trees attended by large numbers of ants than in other parts of the same orchard entirely free of the ants. Trees severely infested with the soft brown scale have been rapidly freed by the action of parasitic insects following the control of this ant.

It is entirely possible that the Argentine ant distributes fungous and bacterial diseases, although no specific evidence has been noted. Attracted as they are by the honeydew of insects, their habit of carrying this and various other substances, both animal and vegetable, their colonization and movement over the ground, and their constant attendance to all parts of the trees offer ready means of distributing brown rot, gum disease, and other maladies of citrus. In this connection ants would appear to be especially deserving of attention in pear orchards through their possible relation to blight.

OTHER RELATIONS.

Beekeeping in sections heavily infested with the Argentine ant is most difficult and proves successful only after a strenuous campaign is instituted to control or exterminate the pest. The ant is exceedingly fond of honey and, furthermore, attacks the bee larvæ. The ant's small size, great numbers, and persistent effort to reach desired food make it an enemy with which the bees are unable to cope long.

As a household pest the Argentine ant has proved particularly annoying. It invades all parts of the house in search of food, and the intolerable conditions brought about in heavily infested districts render the houses less desirable for places of residence.³

DISTRIBUTION.

The Argentine ant appears to have been first noted in California in 1905 by Dr. E. S. G. Titus, at Ontario, although it did not come into prominence until 1908, when a general survey of its dis-

³The rôle of this insect as a household pest has been fully described by Mr. E. R. Barber of this department in Farmers' Bulletin 1101, United States Department of Agriculture.

tribution was made by Prof. C. W. Woodworth, of the University of California. It was then reported as widely distributed about the San Francisco Bay region and in Southern California at Azusa and Upland. By 1910 the total territory involved was estimated at 4,000 acres in northern California and 1,000 acres in the southern part of the State. During the 10 years intervening between the second survey of Prof. Woodworth and to-day this ant has greatly extended its area of occupation, spreading into the great interior valleys of northern California, and including within its limits localities in every county in the south excepting one, as follows: Los Angeles, 39; San Bernardino, 8; Riverside, 4; Ventura, 5; Santa Barbara, 5; Orange, 10;

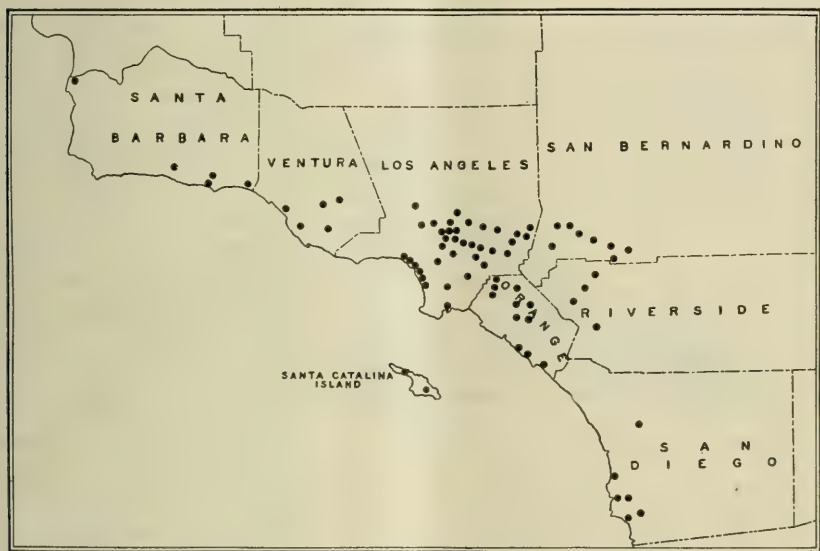


FIG. 2.—Present known distribution of the Argentine ant in Southern California.

San Diego, 6. Two heavy infestations have been observed on Catalina Island, off the mainland of Los Angeles County. (See fig. 2.) The infested territory appears to fall for the most part within cities and towns, although the country acreage concerned is very large, between 8,000 and 10,000 infested acres being known in citrus alone.

Elsewhere in the United States the Argentine ant has been reported to occur in settled localities throughout the Southern States, being established as far north as Nashville, Tenn., and Raleigh, N. C. First described from Argentina it has since gained a foothold in other parts of South America, in the Madeira Islands, South Africa, and Germany.

CHARACTERISTICS AND HABITS.

The Argentine ant, like most other species of ants, forms definite colonies or ant communities under the surface of the ground. The colony or nest is an elaborate system of galleries and cells, closely connected, with usually only two or three openings to the surface.

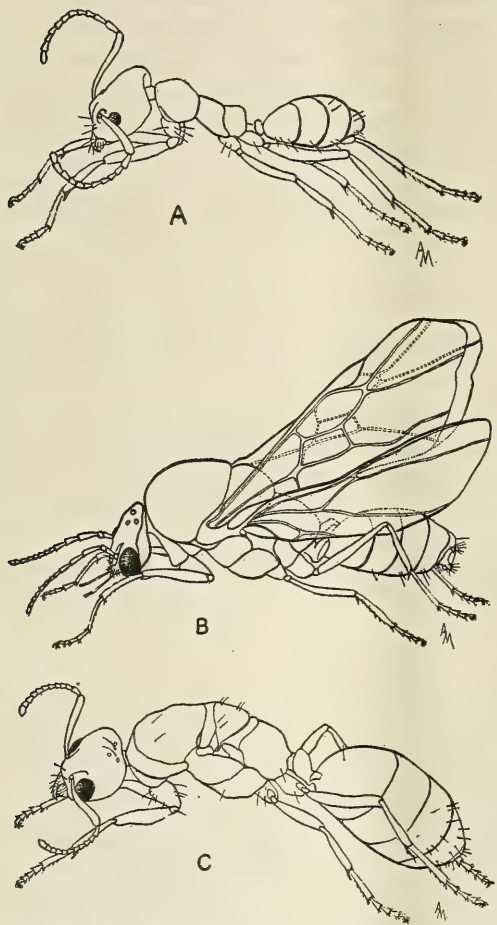


FIG. 3.—The Argentine ant: *a*, worker; *b*, male; *c*, queen.
(Greatly enlarged.)

Though the galleries may cover an area of over 10 square feet they seldom are more than 8 or 10 inches in depth. Colonies are located in places which will afford protection from excessive moisture and give the proper warmth; in orchards during the winter they are invariably on the sunny south side of the trees, usually just beyond the drip of the branches, but in summer they are more often on the east or north margin. In a well-infested orchard under cultivation each tree has a definite and complete colony. The favorite places for colonies about a residence are under cement sidewalks, the foundations of the buildings, a pile of rubbish, the compost heap, or a chicken yard.

The size of the community varies greatly with the season, the food supply, and the age of the colony.

In a normal summer colony the ants will be found in all stages of development—eggs, larvæ, pupæ, workers, males, and females—and the colony responds quickly to warm days and an abundance of food by increasing its numbers. If the colony grows rapidly and the food supply warrants it, or if the food supply is some distance from the main colony, a new community will be started nearer the source of supply by a migration of part of the former colony along the trail established. This expan-

sion of the colony usually occurs in the early spring and summer months. In the late fall (November) the outpost communities are usually abandoned and large central winter colonies are formed in more favorable locations having better drainage and sun exposures. The activities in these communities are limited, fewer workers are sent out in search of food, the male form disappears, reproduction almost ceases, and the number of ants is reduced. Several colonies dug up in December, 1919, and January, 1920, showed a large number of workers in the colony with only a light trail going out in search of food, a number of females, no males, few if any eggs, a few matured larvæ, and numbers of pupæ. Renewed activities in these colonies and the division of the central colony usually occur in early April, though the time may vary somewhat with the season.

As stated, the summer colony is composed of three distinct forms of adults—workers, males, and queens. (See fig. 3.) The workers gather the food and attend to the labors of the community and are simply imperfect females with no reproductive capacity. They greatly outnumber the other forms and are the ones most commonly met with. The males, always winged, are the drones of the colony and have only one function, that of fertilizing the queen. The queens are the reproducing females and for a short time during the mating period are winged. They remain in the nest most of the time, but occasionally may be found out in the trails—a characteristic of this species (fig. 4). It is absolutely necessary that a fertilized queen accompany a number of workers if a new colony is to be established, as the workers alone have no means of reproduction.

The winters in southern California, though occasionally wet enough to retard the development of the ant colonies and force them to winter quarters, are so often broken by short, warm spells and the average rainfall is so light that trap nesting has proved ineffective and seldom are any of the colonies destroyed by excessive moisture.

The preferred food of the ants in orchards is the honeydew secreted by certain scales and aphids, the honeydew from blossoms, and the bodies of certain soft-bodied insects. The workers are very active in collecting this food and may be observed returning along the trail from a foraging expedition, their abdomens greatly distended with liquid food, or their strong mandibles securely clasping their prey. About residences the ants are more or less scavengers, feeding on bits of food wherever they can find it, but frequently invading pantries and even ice chests in search of meats, sugar, sirups, fruit, etc. Their trails may be extended to any part of the building in search of food and often during the first few hot days of summer the ants storm the house.

An interesting feature in the distribution of this ant is that it has completely replaced all native species, with possibly two exceptions,

wherever it has become established. Only on the margins of the Argentine ant infestations does one find colonies of the native Pre-



FIG. 4.—Characteristic trails of the Argentine ant on a tree trunk.

nolepis, Formica, and others. They have repeatedly been observed to dislodge the large red agricultural ant (*Pogonomyrmex californicus* Buckley) from its nest, though sometimes this species persists for a

considerable period. Often after the Argentine ant has been eradicated in an orchard by control means the native ants will come in, but gradually the area will be retaken by the imported ant unless prevented. In comparison to this it is interesting to note the social habits of Argentine ants among themselves. They do not fight one another nor do members of different colonies disagree. In fact, trails from different colonies often converge and an interchange of workers may take place.

The workers are active throughout the day and night and feed almost continuously if not affected by temperature conditions. On cool, foggy, or frosty mornings with a temperature below 50° F. the activity of the ants is greatly retarded and they become slow and sluggish in their movements. Small colonies become almost inactive. Only a small percentage of the workers leave the colony to forage, the majority remaining to protect and care for the ant nest.

CONTROL.

The development and spread of the Argentine ant appear to be governed very largely by food supply and meteorological conditions. From natural enemies such as exert a restraining influence on most injurious insects this species is remarkably free and no record of even temporary control by this means has come to notice in the history of the pest in this country. Therefore, artificial control is the one source of relief once the ant has become established.

The first efforts toward control of the Argentine ant on citrus trees in southern California were made in July, 1915, and confined to banding with commercial sticky tree-banding material, a substance widely used to prevent insects ascending plants. Further experiments in repressive measures, including the use of the sticky material compounded with other substances, banding with corrosive-sublimate tape, and the use of pyrethrum and sodium fluorid, were carried on until the appearance, during the latter part of 1916, of Bulletin 377 of this department, by E. R. Barber, which presented for the first time a successful method of ant eradication. The superiority of eradication over control by repressive measures was immediately apparent, and subsequent experiments have been carried out with this in mind.

BANDING.

STICKY TREE-BANDING MATERIAL.

EXPERIMENT 1.

During the latter part of September, 1915, an experiment with sticky tree-banding material was started in an orchard of 1,135 trees, each of which was attended by heavy trails of ants. Bands $3\frac{1}{2}$ to 5

inches in width were applied directly to the trunks and the ants above the bands removed by the use of insecticides. Inspections were made at least biweekly for a period of six weeks following the start of the experiment and these bands were refreshed at the time of inspection and the ants removed from the body of the tree. During the course of the experiment upward of 70 per cent of the trees became reinfested. The cost for labor and materials to keep the ants in this 10-acre orchard under control by the use of bands amounted to approximately 15½ cents per tree, proportioned as follows:

Labor for pruning and banding 1,135 trees.....	\$75.00
Sticky tree-banding material.....	22.80
Labor for inspection and treatment for ants.....	60.00
Material for ant treatment.....	10.00
Hand pump.....	10.00
Total cost.....	177.80
Cost per tree.....	0.156

It was quickly determined that constant surveillance and frequent combing of these sticky bands are necessary to keep trees free of ants.

EXPERIMENT 2.

Another experiment was performed, in which 120 orange trees were banded with sticky tree-banding material February 21–25, 1916, after the method used in Experiment 1. The ants were present in very light trails, due to retarded development during the winter months. This experiment was inspected weekly for a period of four months, at each visit the bands being refreshed where necessary, infested trees freed of ants, and all growth beneath the tree removed. The results of this inspection are given beneath.

	Per cent of bands crossed.
March.....	37
April.....	5
May.....	10
June.....	14

The bands in this second experiment proved decidedly more effective than those in Experiment 1. This is attributable to several causes. The work was started at a time when the weather was cool and the ants not numerous. In fact they were not abundant at any time during the experiment with the exception of a very few trees on which the bands were not continuously effective. Colonies were removed to neighboring trees where food was abundant and, furthermore, the bands were continuously in a good state of repair. Experiment 1 was started in September when the ants were steadily streaming up every tree to attend heavy infestations of mealybugs.

The size of the orchard prevented each band receiving the same careful attention given in Experiment 2. Instances were noted during the autumn where the bands on slightly attended trees were bridged within an hour following the application.

CONCLUSIONS.

The conclusion to be reached from these two experiments is that the constant attention required to make sticky tree-banding material an effective barrier to ants on heavily infested citrus trees renders the method impracticable in orchard work. It might be used to advantage on a few trees which can be given the necessary attention, as, for instance, on house lots or about buildings.

The general belief that sticky tree-banding material is injurious to citrus trees when applied directly to the bark has been found erroneous. The writers have never seen a citrus tree killed as a result of this treatment. In 1915, 40 three-year-old nursery trees were banded. Examination of the bark beneath the bands one year after application showed the bark perfectly green and healthy. The sticky material on 100 trees banded in September, 1915, was scraped off in July, 1916. In no instance was there certainty of injury to the bark or cambium. Examination of hundreds of trees which have been banded with sticky material for periods ranging from 1 to 5 years have failed to show definitely a single instance of severe injury attributable to the bands. A disease known as gummosis is prevalent throughout southern California especially on heavy soils. Exudation of gum from this disease, beneath the bands or closely adjacent, and the accompanying diseased tissues revealed by removing the band, have been sometimes attributed to the banding with sticky material, although no cases have been observed where this was definitely the cause. Applications to trees soon soften the bark beneath somewhat. After about one year the exposed surface of the sticky material becomes glazed and by the second year a hard exterior coating is found and only the substance adjacent to the tree remains moist and sticky. In due time, depending on the thickness of the sticky layer, the entire band becomes hard, and subsequently is broken by the expanding growth of the trunk. The bark where exposed to the air dries and assumes its normal consistency and appearance. Heavy bands may require several years to dry.

Possible injury from sticky tree-banding material might arise from removal of heavy bands within a year following their application or before they are somewhat dried out. In one case trees heavily banded in September were scraped the following July. The bark was so injured by the workmen in removing the sticky material that a very weak solution of corrosive sublimate was used to disinfect

the wounds. The ultimate effect was such rapid drying of the scraped tissues that great flakes of bark peeled off, temporarily injuring the trees, although they soon recovered. When sticky bands are to be removed, therefore, this should be done without scraping the bark and the thin film will assure gradual drying of the bark without subsequent injury.

AXLEGREASE AND STICKY TREE-BANDING MATERIAL.

A mixture compounded of 1 part of ordinary black axle grease and 2 to 3 parts of sticky tree-banding material recommended by J. R. Horton ⁴ was tried on a large number of trees in different localities. This material proved inferior to undiluted sticky material. A few hot, dry days in summer usually caused sufficient hardening of the surface for the ants thereafter to cross at will.

SULPHUR AND STICKY TREE-BANDING MATERIAL.

By far the most satisfactory "tree-sticky" substance tried was a mixture of sulphur and commercial sticky tree-banding material in the following proportions: ⁵

Finely pulverized flowers of sulphur.....	parts by weight..	1
Commercial sticky tree-banding material.....	parts by weight..	6

The two materials should be thoroughly mixed until of a uniform consistency. In small quantities this should be done with a wooden paddle, although for large amounts that method is too slow and costly. The most satisfactory method observed by the writers for preparing large batches was a turning machine such as a lathe to which was attached a large corkscrew arrangement. A gallon pail partly filled with the proper proportions of ingredients could be mixed to proper consistency in a few minutes and with little effort. The attempt of one orchardist using a shovel to prepare the mixture in 100-pound lots naturally gave a very unsatisfactory mixture, with the sulphur in lumps, rather than a smooth, consistent mass as desired.

After preliminary experiments had proved that the bands of sulphur and sticky material were superior to all other tree-banding materials used, they were given a very extensive tryout over two seasons under widely differing climatic conditions. The results were variable. In one experiment in which 42 large trees had a heavy 5-inch band applied May 1, only 2 had been crossed by August 14, a period of 3½ months. Three adjacent plots comprising a total of 208 trees, for the most part with limbs 3 to 4 inches in diameter, were treated with bands 2 to 2½ inches wide. From 18 to 34 per cent of these bands were crossed within one month. In

⁴ HORTON, J. R. SOME WEATHERPROOF BANDS FOR USE AGAINST ANTS. *In Calif. State Comm. Hort. Monthly Bul.*, v. 5, no. 11, p. 420. 1916.

⁵ HORTON, J. R. *Op. cit.*

another case of several hundred trees banded with a poorly prepared material, showing granules of free sulphur, a very large proportion of the bands were crossed within a few days following the application. Experience has shown that heavy 4 to 5 inch bands of a mixture of sulphur and sticky banding material thoroughly protected from the sun will keep in good sticky condition during dry weather for a period of 2 to 3 months, or even longer. If exposed to the sun at all, a dry film quickly forms and the ants cross at will. Furthermore, the direct sun causes the material to become very soft and to run down the trunk.

Although there is no particular reason why the addition of sulphur should cause the sticky material to be injurious to the bark of a tree the precaution was taken in all our experimental work to apply first a protective substance. (See fig. 5.) At first 3 to 4 inch bands of oilcloth were applied to tree trunks by means of adhesive tape attached to the upper and lower surfaces, and the tree-banding substance was applied to this band. The difficulty experienced in covering irregular tree trunks with such bands led to search for an innocuous substance that could be painted onto the trunk and the most satisfactory material tried was paraffin. This was first melted and kept at a temperature just above the melting point when applied to the tree trunk. A paint brush proved satisfactory for the work. The paraffin under no circumstances should be at a very high temperature, else it will penetrate deeply into the bark. The requirement is a superficial layer. While the ordinary grade of paraffin recommended for home canning proved satisfactory in thoroughly shaded trees in the coastal districts, in the warm interior valleys, on tree trunks sometimes reached by the sun, they melted on the sunward side and deeply penetrated the bark, causing considerable injury. This necessitated the use of a paraffin with high melting point, one exceeding 130° F. Such paraffins are purchasable of oil-refining companies or dealers in technical supplies. *The caution should be observed, however, that under no circumstances should trees be banded with sulphur and tree-banding sticky material over a paraffin band in situations reached by the direct sun.*

COST.

In 1916 the average cost per tree banded with this mixture was 7 to 8 cents, exclusive of removing the weeds beneath the trees and pruning the branches. At present the cost would approximate 15 cents.

PYRETHRUM AND SODIUM FLUORID.

Sodium fluorid and pyrethrum were used singly or in mixtures and applied to the crotches of trees or on cotton bands around the trunks. (See fig. 6.) The cotton bands usually rid the trees quickly

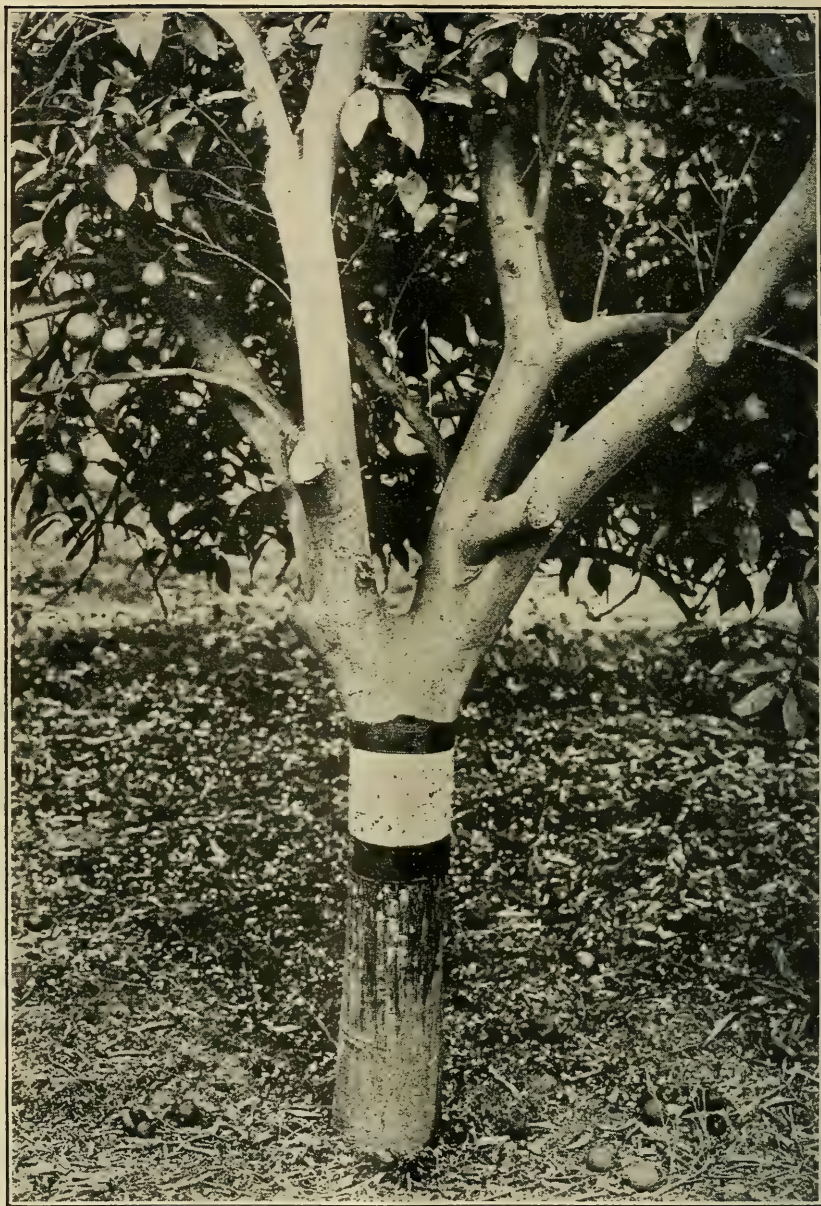


FIG. 5.—Keeping ants off citrus trees. A 5-inch band of sulphur and commercial sticky tree-banding material over a wider coating of paraffin. (Woglum and Neuls.)

of ants but their effectiveness was lost upon exposure to the weather. Once wet these insecticides are valueless. These powders, especially the pyrethrum, singly or in combination with the sodium fluorid, are decidedly repellent to ants and quickly cause death once they come well in contact with their bodies. The fact that their strength is soon lost on exposure to air restricts their usefulness.

The following experiments demonstrate the comparative efficiency of these substances used singly or in combination. Breeding cages containing a large amount of mealybug-infested lemons and potato sprouts were heavily attended by ants which entered in steady streams along the legs. The legs were set in tops of fruit jars containing a small amount of sodium fluorid powder. Ants continued to cross in limited numbers for about one hour before the trails were completely broken up. No dead ants were found.

Pyrethrum powder was sprinkled about the legs of one cage, stopping the trails almost immediately. Dead ants began to pile up in the powder and on the floor about the powder.

A mixture containing pyrethrum 1 part, sodium fluorid 7 parts, and plaster of Paris 2 parts, was dusted about the legs of a breeding cage attended by ants with effects about as satisfactory as with pyrethrum alone.

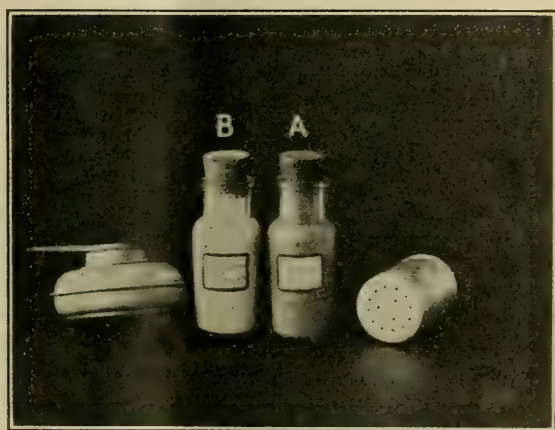


FIG. 6.—Repellent ant powders: a, Pyrethrum; b, pyrethrum 30 per cent, sodium fluorid 70 per cent. Shaker and blower for applying.

CORROSIVE SUBLIMATE ANT BANDS

Corrosive sublimate has long been known to possess merit as a repellent to ants and this fact has been utilized in protecting materials from these pests. A common method is to soak narrow strips of cloth in a saturated solution of this chemical and use these as barriers. The saturated solution is best prepared by heating about $1\frac{1}{2}$ ounces of corrosive sublimate in an ounce of water until the maximum amount is dissolved. The solution is then allowed to cool, is filtered, and the cotton band or tape is soaked in it for several hours. The tape is then removed, allowed to dry, and is ready for use. This amount of solution is sufficient for from 10 to 12 yards of $\frac{3}{4}$ -inch tape.

Several small nursery trees infested with the cottony-cushion scale, *Icerya purchasi* Maskell, attended by ants, were banded with such tape to determine its effectiveness against the ants, as well as its effects on the trees. The trees were quickly freed of ants and remained so throughout the experiment. The tape, however, soon killed the bark down to the wood and the trees ultimately died.

Fourteen large orange trees were banded with mercuric bichlorid ant tape on September 10, 1915, the tape being wound around the tree several times to form a band several inches wide. The bark was protected from the band by heavy paper. On October 10, one month after the bands were placed, an inspection showed that 5 of the 14 bands had been crossed. These had been rendered ineffective by heavy fogs.

The great danger attendant upon the use of corrosive sublimate, its ineffectiveness when exposed to moisture, and its high cost render this substance generally impractical for repelling ants. It is, however, of special value for protecting apiaries which are seriously troubled by this pest. Newell and Barber,⁶ working in Louisiana, invented a four-legged hive stand from which they were able to keep the ants for many months by winding ant tape about the legs. The writers have tried a similar stand under California conditions with success, even where honey and other substances attractive to ants were profusely scattered over the top. Equally satisfactory with the ant tapes was found a mixture of mercuric bichlorid and shellac which could be applied directly with a brush. A formula adapted from Horton⁷ consists of:

Corrosive sublimate.....	gm..20 or oz.. $\frac{1}{4}$.
Alcohol.....	cc..60 or oz..2.
Shellac.....	gm..31 or oz..1.

The corrosive sublimate is first dissolved in the alcohol, then the shellac added, and the mixture shaken until all is dissolved.

FREING TREES OF ANTS AFTER BANDING.

Freeing trees of ants after banding is an essential part of tree isolation. Heavy infestations of ants at the time of banding will sometimes form a crossing over bands of sticky material from the accumulation of entangled bodies of ants which have attempted to escape from the tree. With corrosive sublimate or ant powders such attempted crossing in no way affects the efficiency of the bands; in fact, on such banded trees ants usually drop off before making an attempted crossing and the trees become free of ants unless colonies are already present in cracks or accumulations of débris in the crotches. Many

⁶ NEWELL, WILMON, and BARBER, T. C. Op. cit., p. 88-91, figs. 11-13, Pl. VII.

⁷ HORTON, J. R. THE ARGENTINE ANT IN RELATION TO CITRUS GROVES. U. S. Dept. Agr., Bul. 647, p. 64. 1918.

large trees support aerial colonies during the warm season and not infrequently colonies have been noted in midwinter.

Several methods of freeing banded trees were tried. The first method was to spray the trunk and main branches with such insecticides as carbolic-acid emulsion or distillate emulsion immediately after banding, the application being made with a compressed-air pump holding 3 gallons. This proved too slow and ineffective, as ants are actively engaged throughout the tree during the day. It was soon observed that the early morning was the proper time to



FIG. 7.—Plumber's torch for applying certain sprays to rid a banded tree of ants.

destroy the ants above the bands, for they are sluggish at the cool temperatures and have the habit of congregating in crotches or in their aerial nests. The compressed-air pump was soon discarded in favor of a plumber's hand torch (fig. 7), in which gasoline or a weak cyanid solution was used as a spray. This in turn gave way to the use of pyrethrum or other ant powders which proved simple of application, economical, and immediately effective. Nests in tree crotches or elsewhere could be quickly freed by a single application, and for this purpose either a small bellows or shaker (fig. 6) proved satisfactory.

SUMMARY OF USE OF REPELLENTS.

Although the writers' experience with banding demonstrated that trees could be kept freed of ants by careful and diligent effort, it was apparent that the constant attention needed for success would not be forthcoming where large acreages were concerned. Furthermore, the method of pruning followed in some orchards produces trees so low that growers seriously object to removal of the large amount of growth necessary for tree isolation except at the trunk. Even after pruning the increasing weight of the fruit weighs down the branches and cultivation frequently breaks small twigs which demand additional attention. Grass and weeds quickly spring up beneath the trees and in contact with a tree leaf furnish a bridge which is invariably discovered by the ants. In fact the ants may find access to a tree by way of a blade of grass which comes in contact with a leaf of the tree momentarily stirred by the wind. In one case a branch of a banded tree rested against a telephone pole and gave a means of reaching the tree. The branch was pruned and the telephone pole banded, yet the infestation persisted. It was finally discovered that the ants crawled along a guide wire to the top of the telephone pole, and thence down to a part where a single leaf momentarily touched the pole as moved by the wind. This was the signal for the persistent little pests quickly to mount the leaf while others moved to the pole.

The glazing of sticky bands where exposed to the sun, the accumulation of falling petals during the blossoming season, the spattering of dust over the bands during rains, or the washing down of dust, leaves, broken twigs, and the materials collected during heavy windstorms, all contribute to render banding with adhesive mixtures impractical over large acreages. In spite of all these drawbacks bands can be made to serve a useful purpose on limited numbers of trees, especially about yards where necessary attention and renewal or respraying can be given. It should be borne in mind, however, that banding merely repels without destroying ants, and destruction is what is actually required.

TRAP NESTING.

The discovery that large boxes filled with decaying vegetable matter would attract ants in numbers in winter induced Newell and Barber to try this plan in infested orange orchards in Louisiana, and their efforts were reputed to have met with great success in reducing the infestations. The trap boxes were subsequently fumigated and the ants destroyed. Horton⁸ also recommended the use of trap nests as by far the best and most practical means of destroying the Argentine ant in the orange groves of Louisiana. The great

⁸ HORTON, J. R. CONTROL OF THE ARGENTINE ANT IN ORANGE GROVES. U. S. Dept. Agr., Farmers' Bul. 928, p. 12-16. 1918.

success attending this method in the Southeast induced the writers to conduct an experiment under the more arid conditions in the Southwest.

A 10-acre orange grove at Upland, Calif., very severely infested with Argentine ants, was selected for the experiment. Five-gallon tin coal-oil cans ($9\frac{1}{4}$ by $9\frac{1}{4}$ by $13\frac{1}{2}$ inches) were used for traps (see fig. 8), being much cheaper than the wooden boxes, and affording complete protection from rain or winds. One end was cut along three

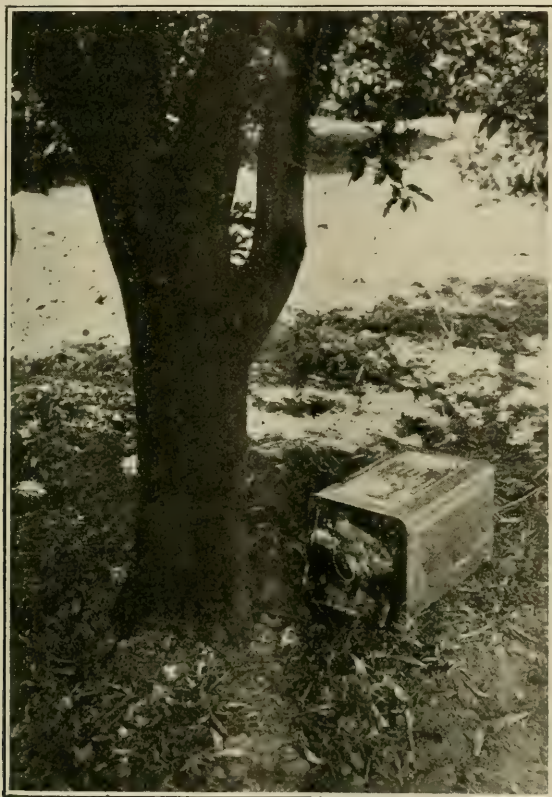


FIG. 8.—Winter trap nest, consisting of 5-gallon oil cans filled with nesting material, in place at base of tree.

sides and this acted as a flap over the entrance of the can, protecting it from beating rains. Three hundred and fifty cans were used, being divided into seven lots of 50, each lot containing a different filler. These were respectively green grass and dirt, green grass, green alfalfa, dry straw, wet straw, moist dirt, dirt, and leaf mulch. The cans were placed on a side, close up to the base of the tree. Approximately 3 of the 10 acres were reserved as a check, the remaining 7 being covered with ant traps, one to each tree on about 3 acres and one to every other tree on the remainder. These were placed December 1, 1917.

An inspection February 7, 1918, showed that some ants had colonized in the cans, but in the absence of heavy rains the ants were continuing largely in their ground colonies. A final inspection March 18, 1918, showed that only 41 per cent of the cans contained nests, and these were for the most part small. Many colonies were found in the ground beneath the cans or even at the base of the trees near the cans; in fact, in all cases the preponderance of ants in the orchard appeared to be outside the cans. The cans were fumigated with carbon disulphid immediately following the final inspection. An inspection of the entire grove in May showed the ants as prevalent in the part over which ant traps were distributed as in the check plot, thus demonstrating the futility of ant control in California by the trap-nest method recommended for Louisiana.

A second experiment in an adjacent grove with 50 trap boxes during the same winter gave no better results.

The success of trap nesting, as pointed out by Newell and Barber, depends upon rainy weather. The winter of 1917-18 was a warm and open one with light rains, and this resulted in ants being more or less active in southern California throughout the season. It is very probable that in a colder winter with heavy rains trap nests would be more successful. Even under the most ideal conditions for trap nesting, however, this method would be less effective and more costly than the poisoned-sirup method later taken up in this publication.

POISONED SIRUPS.

Eradication is the ideal to be sought with any pest and particularly does this apply to the Argentine ant. Once the ant is eliminated from a grove, future effort can be restricted to protecting the borders from invasion from neighboring property. The most effective method of eradication tried in California has been the use of a poisoned sirup, which is eaten by the ants. For the most part arsenic in some form constitutes the toxic substance of such a poison, although a few nonarsenicals have been used.

In all orchard work small containers of tin or paraffined paper were used, partly filled with sirup and hung one to a tree, the ants entering through small holes in the sides.

CHLORAL HYDRATE.

Chloral hydrate was recommended by Horton⁹ as the best poison for orchard use. It is prepared as follows:

Make a sirup by stirring 8 pounds of granulated sugar in one-half gallon of cold water until dissolved, making $1\frac{1}{2}$ gallons of sirup. Then add $4\frac{1}{2}$ ounces of chloral-

⁹ HORTON, J. R. CONTROL OF THE ARGENTINE ANT IN ORANGE GROVES. U. S. Dept. Agr., Farmers' Bul. 928, p. 19. 1918.

hydrate crystals, previously dissolved in a small quantity of water, and about one-half pound of strained honey.

On July 22, 1918, an orchard experiment was started in which 2-ounce spice tins about one-third filled with chloral-hydrate sirup according to the foregoing formula were hung on 48 trees attended by heavy trails of ants. The ants fed on this sirup greedily when first distributed and continued feeding freely throughout the duration of the experiment, which was five months. The sirup started crystallizing about one month after being distributed and within six weeks most of the containers were partly filled with large crystals resembling rock candy. Although the sirup proved attractive, it did not appear to reduce the numbers of ants more rapidly than they bred, for ants were almost as numerous at the completion of the experiment as at the beginning. The tendency of this sirup to crystallize and its only partial action against ants show it to be not fully satisfactory as a poison.

ARSENICAL POISONS.

Arsenic in large quantities acts as a repellent to ants and its earliest use against the Argentine species was based on this action. Woodworth, experimenting later with this insect in the San Francisco Bay region of California, obtained success in control by the use of an unboiled sweetened poisoned sirup containing about one-fourth of 1 per cent of sodium arsenite.

In 1916 E. R. Barber¹⁰ published the results of his efforts against the ant in Louisiana with an improved arsenical sirup and showed for the first time that eradication was possible over extensive areas. This system immediately appealed to the senior writer as offering a more practical solution of the ant problem in California than banding, which he had previously been using, and accordingly an experiment in controlling the ants about the laboratory was started in October, 1916, and met with marked success. In December, 1916, an orchardist, who had observed the effectiveness of the system installed on the laboratory grounds, attempted control on his property by this method. This was the first control attempted in southern California in a citrus orchard. Others were thereupon induced to adopt the methods which Mr. Barber had proved eminently successful in Louisiana, and at the same time the writers started an investigation of the use of this poison under California conditions. This led to experimenting with various other formulas containing arsenic as the basic poison and the ultimate development of a formula thoroughly satisfactory under California conditions.

¹⁰ BARBER, ERNEST R. THE ARGENTINE ANT: DISTRIBUTION AND CONTROL IN THE UNITED STATES. U. S. Dept. Agr., Bul. 377. 23 p., 5 fig. 1916.

ORIGINAL BARBER FORMULA.

Orchard A. The owner of a 10-acre orchard of large Valencia and naval orange trees located at Alhambra in a district overrun with the Argentine ant was induced to attempt control by the use of the poisoned sirup which had proved so successful in Louisiana. This work was done under contract and the poison prepared according to the original Barber formula as follows:

Granulated sugar.....	pounds..	15
Tartaric acid (crystallized).....	ounce..	$\frac{1}{4}$
Sodium arsenite C. P.	do.....	$\frac{3}{4}$
Honey.....	pounds..	$1\frac{1}{2}$
Water.....	pints..	8

A special 1-pound paraffined paper sack punched with a few small holes and containing about an ounce of sirup and a 1-inch cube of sponge was attached to each tree, either on the trunk or one of the main branches. The orchard was in a state of clean cultivation with no grass or weeds beneath the trees, and in most cases the lower limbs were entirely free of the ground, so that the trunk formed the only means of access to the tree for the ants. The distribution of filled containers was made on May 14-15, 1917. No inspection was made at the time of sirup distribution, although during the previous autumn trails of ants were present on every tree, and a careful examination in April showed heavy streams of ants on trees in all parts of the orchard.

Some of the paper bags lost their contents soon after distribution and these were replaced in the latter part of June. The sirup thickened rapidly during the summer and by the first of August, or probably two months after the experiment was started, the contents of many bags had commenced to crystallize or solidify. When this stage was reached, it was noted that the sirup no longer proved so attractive to ants. A few bags were refilled in August, and in September fresh sirup was placed in all containers.

After the sirup was distributed frequent inspections of this orchard were made throughout the season of ant activity and notes taken on the progress of the control and eradication. These results were most encouraging and showed conclusively not only that orchard control of the ant was possible, but that the ant could be eradicated by persistent effort.

The experiment began on May 14, with most of the trees in the orchard heavily attended by trails of ants; by May 22, or within a week's time, these had been reduced to only 26 per cent with trails; and within two weeks to 11 per cent. By July 19, or two months after the poison was distributed, the ants had either been entirely destroyed or reduced to within the limits of control on 98 per cent

of the trees in the orchard. With the approach of the middle of August the ants were practically controlled throughout the orchard.

Progress (fig. 9) is naturally slower from the standpoint of eradication than of control. For the first month eradication of ants from trees was constant and rapid, 52 per cent of the entire orchard being freed within this time. Then eradication slackened and for the succeeding 6 weeks made no noticeable gains. By the middle of August an increased number of trees were free of ants and this continued until by the middle of November ants had been eradicated

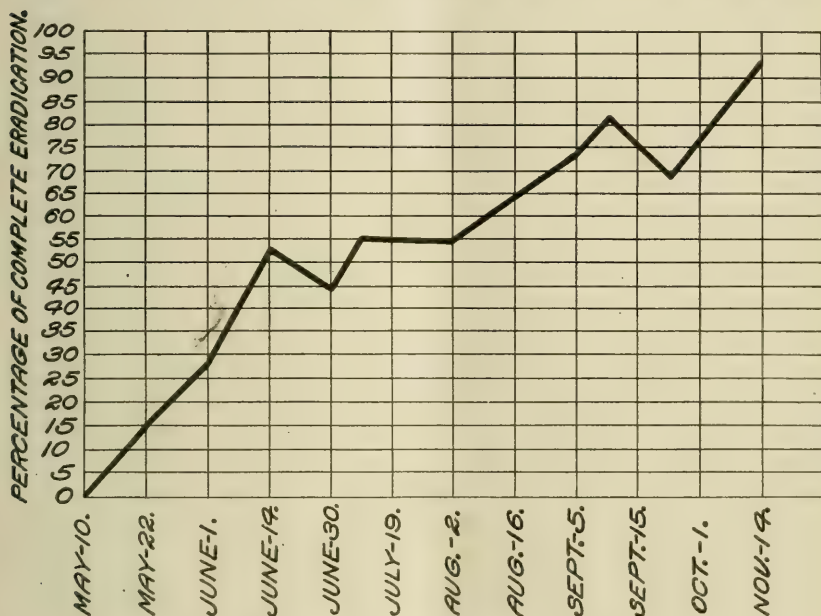


FIG. 9.—Progress of ant eradication on a 10-acre citrus orchard.

from 92 per cent of the trees, those remaining being mostly marginal and attended by a few stragglers from adjacent property.

It should be noted in presenting the marked success of this experiment that the trees were quite free of scales, although a few mealybugs were present. Therefore the food supply was not particularly abundant. Likewise worthy of note is the fact that this orchard had been severely infested with *Pseudococcus citri* for four years prior to ant control but since then this pest has been effectively controlled by its natural enemies.

TABLE 1.—*Effectiveness of Barber poisoned sirup in the control of the Argentine ant in a citrus orchard.*

	Dates of inspections.										
	May 22.	June 1.	June 14.	June 30.	July 19.	Aug. 2.	Aug. 16.	Sept. 5.	Sept. 15.	Oct. 1.	Nov. 14.
Free of ants.....	P. ct. 15	P. ct. 28	P. ct. 52	P. ct. 44	P. ct. 55	P. ct. 54	P. ct. 63	P. ct. 72	P. ct. 81	P. ct. 69	P. ct. 92
Trails of ants.....	26	11	11	4	2	1	$\frac{1}{2}$	$\frac{1}{2}$	0	$\frac{1}{2}$	0
Few straggling ants.....	59	61	37	52	43	45	36	27	19	30	8
Either free of ants or with few stragglers only.....	74	89	89	96	98	99	99	99	100	99	100

Orchard B, located at Upland, Calif., consisted of 6 acres of Valencias and 4 acres of naval oranges, with a total of 674 trees. They were very large, being about 25 years old, and quite severely infested with the citrophilus mealybug. The lower limbs which rested on the ground were trimmed up, thereby forcing the ants to ascend the trunks. The orchard was in a clean state of cultivation with no vegetation growing beneath the trees. The ant sirup was prepared according to the original Barber formula and put out in 1-pound paraffined paper bags, one to each tree as described in orchard A. The distribution of the sirup was completed October 5, 1917. A careful inspection was made from time to time to note the stability of the sirup and its effectiveness against the ants. Some crystallization appeared within 6 weeks, and by the end of the second month practically all had hardened. The ants fed heavily on the sirup before crystallization took place and their numbers became greatly reduced during the autumn months. Although prior to the sirup distribution only 5 of the 674 trees were free of ants, all the remainder being attended by trails of ants, many having two or even three trails along the trunk, these trails became weaker and weaker and were almost broken by the time the sirup began to crystallize.

There was slight ant activity throughout the winter, due to the open season. On March 3 and 4, 1918, an inspection of the orchard showed above 99 per cent of the trees entirely free of ants, only 3 of the 674 trees being infested. By April 9 ants had invaded the orchard from severely infested adjoining territory, so that 26 trees were infested. Fresh sirup was distributed on these trees at this time, and on June 17 on other marginal infested trees. By June 29 ants had been eradicated from 672 of the 674 trees in the orchard, and the experiment stood as a determination of the efficiency of the poisoned-sirup method in orchard eradication of ants.

Cost.—The cost of ant eradication in these 10 acres, including the materials, labor in preparation, and distribution of 674 containers in October, 26 in April, and 32 in June (a total of 732), amounted to \$19.03, or 2.6 cents per tree.

Crystallization.—The sirup prepared with the formula used in orchards A and B commenced to thicken in from two to four weeks after its distribution in the orchard and crystallization started in from six weeks to two months. Sirup distributed in the dry cold weather of late fall was observed to crystallize in some cases within a month. The sirup proved less attractive to ants as it thickened, and crystallized sirup was little attended. Although the Barber formula proved very effective against the ants under conditions where heavy feeding followed the initial distribution, and control was really effected during the period of normal stability of the sirup, as was the case in orchards A and B, weather conditions and normal food supply of the ants frequently were such that feeding was slight during the early weeks of distribution. If in such cases the sirup became crystallized within a month or six weeks following the distribution its effectiveness against the ants was greatly reduced.

The situation is well presented by the comparison of ant control in a 10-acre orchard adjacent to orchard B, at Upland. The orchard consisted of 676 trees, 76 of which were reserved for control by another system. Ant control by the same sirup as used in orchard B was started in the remaining 600 trees, which were largely navel oranges with ant infestation practically identical with that in orchard B. The distribution took place during the first part of November, or fully a month later than in orchard B, and the sirup crystallized within a month after being put out. Although above 99 per cent of the trees in orchard B were free of ants on March 24, 1918, in this latter orchard only 65 per cent were in this condition. The difference in control is attributable to a shorter period of sirup supply. This crystallization of sirup led to experiments in an effort to secure a sirup of greater stability and possibly more attractive to the ants.

MODIFIED BARBER FORMULA I.

Observations indicated that sirup which had become diluted by rain entering the container was more stable than the more concentrated sirup. This led to the use of a modified formula in which the sugar was reduced from 15 pounds to 12 and the honey increased by one-half pound to compensate for the reduced sweetness. Experiments with this sirup during 1918 proved it to be as attractive to ants as the original formula and its stability was greatly increased, for during the summer it remained without crystallizing for periods up to four months. This sirup was used over a great acreage during 1918 with marked success. With the approach of cold weather it was found that this sirup would crystallize, though much more slowly than the thicker sirup.

Unboiled sirup.—An experiment was started on 50 trees in which the modified Barber formula was prepared without boiling, the sugar

being dissolved in lukewarm water, to which the dissolved arsenic and honey were then added. No tartaric acid was used, for an alkaline sirup, which might prove more attractive to ants, was desired. During the first week the ants fed more freely on the unboiled sirup than on the boiled sirup in an adjacent plot, and at the end of the first month both sirups proved equally attractive. The unboiled sirup then started to turn dark and decompose, after which its attractiveness to ants was greatly decreased. The boiled sirup, however, was in perfect condition at the end of the month and its attractiveness continued. This plainly shows that the unstability of an unboiled sirup renders it less useful than the boiled sirup.

Saccharin.—The shortage of sugar in 1918 led to experiments with substitutes, and of these saccharin, supposedly 600 times sweeter than sugar, was one of the first tried. A formula was prepared using three-fourths of an ounce of saccharin, 2 pounds of honey, and three-fourths of an ounce of sodium arsenite to 2 gallons of water. Three-fourths of an ounce of saccharin is equivalent to 28 pounds of sugar, and at this rate the sweetness of the sirup was approximately twice that of the regular Barber formula. This sirup was lightly attended by ants during the first few days following its distribution, but thereafter proved repellent. Other formulas were made containing decreased amounts of saccharin; but in all cases the sirup proved unattractive to the ants.

Glucose.—Glucose was used in several different formulas as a substitute for sugar. In no case did it prove as attractive or effective as the original or modified Barber formulas.

MODIFIED BARBER FORMULA AND CHLORAL HYDRATE.

A sugar sirup with chloral hydrate as the poison proved highly attractive to ants but did not possess the required killing properties. It was thought, therefore, that chloral hydrate added to the modified arsenical formula might increase the attractiveness of the latter to ants and result in their very rapid eradication. Accordingly, 3 ounces of chloral hydrate in solution was added to 1 gallon of the arsenical sirup and the mixture distributed in containers on ant-infested trees. The ants attended the cans slightly at first, but the sirup proved repellent. Other formulas with greatly reduced chloral hydrate proved equally repellent.

FINAL FORMULA.

The thickening of the sirup in modified Formula I during the summer and its frequent crystallization after protracted exposure to cold weather during the winter led to the preparation of a still more dilute ant sirup, in which 11 pints of water were used instead of 8 pints as previously. This new sirup was first prepared during the spring of

1918, and has since been used on more than 2,000 acres of citrus. It is of thin consistency and greater stability than Formula I. It has proved very attractive to ants and has been highly effective in control and eradication. It was discovered, however, that fermentation of this more dilute sirup sometimes occurred, especially in the damper sections near the coast. This was corrected by the use of benzoate of soda at the rate of 0.1 per cent.

Preparation of final and most satisfactory formula.—The final formula was prepared as follows:

		Cost.
Water.....	11 pints.....	\$0. 000
Tartaric acid (crystallized).....	.7 grams.....	. 016
Benzoate of soda.....	.9 grams.....	. 029
Granulated sugar.....	12 pounds.....	3. 00
Honey, strained.....	.2 pounds.....	. 77
Sodium arsenite, C. P.....	$\frac{3}{4}$ ounce.....	. 047

Total sirup, 2 $\frac{1}{2}$ gallons. Cost per gallon, \$1.54.¹¹

Put 10 pints of water in a clean vessel over a low fire. When tepid add tartaric acid, then benzoate of soda, and then the sugar, slowly, while stirring to prevent burning. Measure the depth of the liquid with a stick. Slowly bring it to a boil and allow it to simmer for from 30 to 40 minutes. Remove from the stove and add water to compensate for evaporation. Stir in the honey before the mixture cools. Then add sodium arsenite which has been dissolved in 1 pint of hot water and partially cooled before being poured into the sirup. Stir thoroughly.

It is necessary that great care be exercised in the selection of the materials used, as well as in the preparation of the sirup. Either cane or beet sugar may be used. The sodium arsenite should be chemically pure. The honey should be strained and free of comb. The sodium arsenite preferably should be dissolved in distilled water to avoid the precipitation which sometimes occurs if very hard water is used. Vessels should be thoroughly cleaned before being used for the preparation of ant sirup, and it is desirable that they be used for this purpose only. Oils and various chemicals are distasteful or repellent to ants, and sirup which acquires a flavor of such substances from the container in which it is prepared or stored may be unattended by the ants. The stability of the sirup depends much upon the way it is boiled. If brought to a boil within a few minutes and boiled vigorously for 30 minutes the stability appears to be much less than if brought to a boil very slowly and then merely allowed to simmer for 30 or 40 minutes. Where several times the amount given in the formula is made in a large vessel the sirup appears to "stand up" best. This seems due to the fact that the sirup does not come to a boil for an hour or longer, and this probably results in greater inversion. The sirup should be used when fresh.* Clean glass bottles are best if the sirup is to be stored.

¹¹ With sugar at present prices (about 10 cents a pound) the cost would be only about \$2 cents a gallon.

CONTAINERS.

BAGS.

One type of container extensively used was a $\frac{1}{4}$ -pound paraffined paper bag (fig. 10.) Well-made paper bags were purchased in large quantities, punched about 2 inches above the bottom with four holes small enough to exclude honeybees, and dipped in molten paraffin of

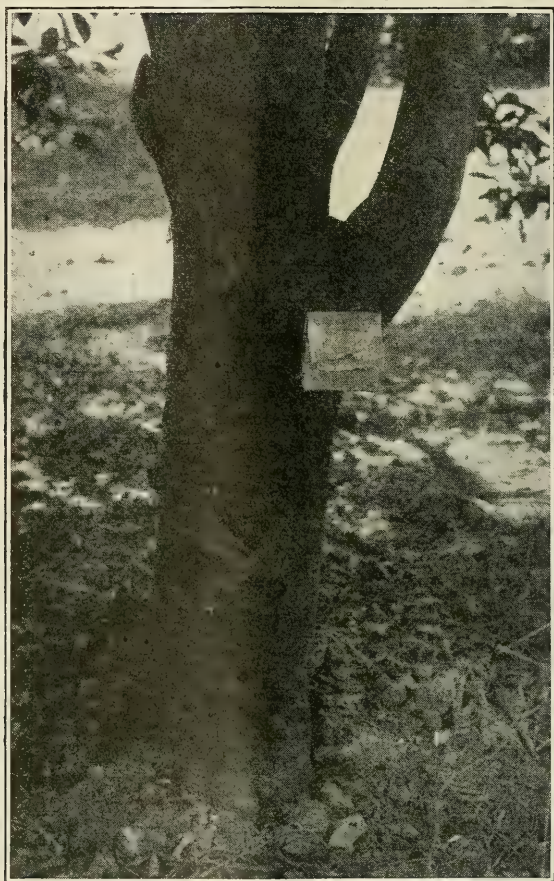


Fig. 10.—A paraffined paper bag in place on tree.

a melting point above 124° F. Paraffin, being highly inflammable, should be removed from the stove during the dipping. The top of the bag is held with a pair of curved forceps or pliers, the bag completely submerged in the paraffin, momentarily drained, and stood top upward on a greased board or tin. This allows the residue paraffin to settle well into the bottom, the part where leakage is most apt to occur. Bags were found to be quite satisfactory and the least

expensive of all containers. They have, however, certain drawbacks. They are prone to leak and wherever the arsenical sirup drips on the bark of a tree injury follows. Therefore it has been found advisable to hang paper sacks to the trunk or main branches so that no sirup will drip on the tree. During the rainy season the unprotected paraffined sacks as used in California collect water and do not stand up well.



FIG. 11.—A paraffined spice tin on tree trunk.

Ants, however, are for the most part inactive at that time, so control is seldom necessary during the winter. One great advantage of paper bags is that feeding by the ants or crystallization of sirup is quickly detected without removal and opening. Paraffined drinking cups or other paraffined containers on the market could be used in orchards for holding ant sirup.

CANS.

Sixteen-ounce round baking-powder tins recommended by Barber were tried in one orchard but proved too large and cumbersome. Several hundred 4 and 8 ounce tins of the same shape were used in experimental plots. These proved more satisfactory. In canvassing the market for different types of tins available in quantity at a reasonable price it was found that the 4-ounce oblong spice tin with plain cover (fig. 11) met the requirements most closely. Such tins are crimped without solderings and are not water-tight at the seams. It was found that dipping these cans in paraffin of high melting point covered both the inside and outside with a thin, almost invisible

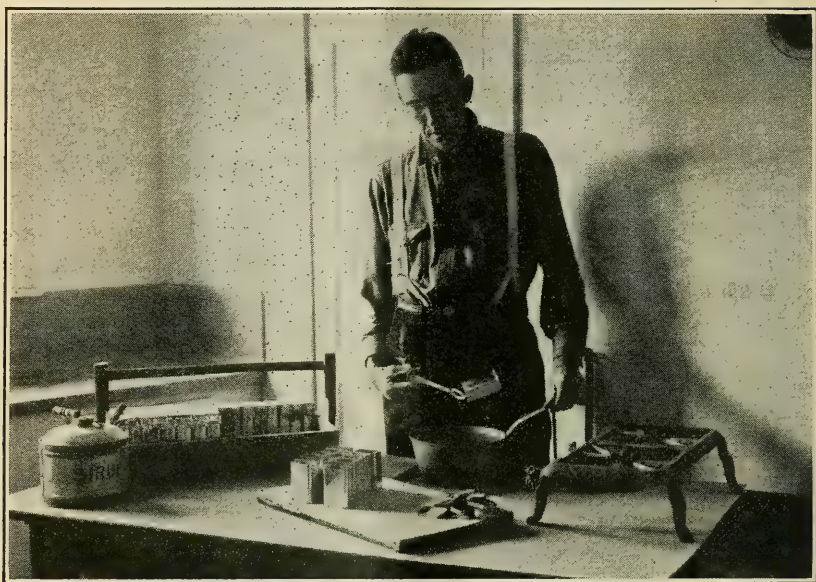


FIG. 12.—Method of paraffining spice tins for use in the field.

coating, prevented leaking, and rendered them rust-resistant. (Fig. 12.) One small hole was punched in a side about 1 inch below the top and the can hung by it on the tree over a 2d. finishing nail. These cans have proved the most satisfactory of all containers. They lie close to the trunks of the trees and are not moved by either wind or rain. When the ants are sluggish, as they are in cold weather, not uncommonly they cluster beneath the can and this doubtless increases their feeding.

GROUND TRAPS.

In control work about houses, especially where there are large lawns, and also in conservatories where water is freely used, water-tight round cans are advantageous. These are set in the ground along

the main runways of the ants. A small baking-powder can with friction cover indented in two or three places immediately beneath the cover to allow passage of ants would prove satisfactory. Such a can is being used in Louisiana. A very successful lawn trap used in California consists of a pimienta can protected by a special cover attached to a 6-inch stake. (Fig. 13.) A hole is made in the grass large enough for the can. The stick is then set into the ground until the cover fits firmly over the can. When these covers are painted foliage-green and sunk even with the grass they are inconspicuous. The lawn can be mowed or watered without destroying the sirup or container.



FIG. 13.—Types of ground traps: *a*, A small baking-powder tin with the edge bent to permit passage of ants; *b*, a special ground trap used in California for control about residences.

FILLING AND DISTRIBUTING CONTAINERS

It has been found most practical to fill the containers in the field. The cans or bags are prepared beforehand and taken into the orchard.



FIG. 14.—A convenient type of tray for field distribution of poison containers, and a 1-gallon can for holding poisoned sirup.

These are arranged on trays as shown in figure 14. A gallon can with a long spout is handy for filling. In each container three-fourths to one inch of sirup is used and this in reality averages about $1\frac{1}{2}$ ounces. At first small cubes of sponge were used in each can or bag to increase the feeding surface. It was soon discovered that the sponges hastened evaporation and thick-

ening of the sirup and were thus a disadvantage rather than an asset. A very satisfactory substitute for the sponge was found in excelsior and four or five clean strands about a foot long were folded very loosely in the can or preferably suspended from the top, as shown in figure 15. Under no circumstances should a large, heavy, compact wad of excelsior be used. The advantage of the loose strands is that they furnish an attractive runway for the ants, reduce the likelihood of their

becoming entangled in the sirup, and at the same time increase the feeding area. When folded into a compact mass excelsior is unsatisfactory and tends to obstruct the free passage of ants, and furthermore absorbs much of the sirup unless the can is well filled. Excelsior has entirely displaced sponges in California.



FIG. 15.—A spice tin with front removed to show amount and arrangement of excelsior.

After the spice tins or bags are filled, the tops are put on or the upper part of the bag folded, and they are then ready for attachment to the tree. (Fig. 11.) The bags are tacked as shown in figure 10. The cans are hung on a small finishing nail which is first driven into the tree. The containers should be on either the trunk or main branches on the shady side of the tree.

REFILLING.

The writers have practiced and advocate monthly inspections. A tray of filled containers should be carried along and where an empty, missing, or crystallized container is found it can be replaced. If crystallization is general all containers should be removed. Fresh sirup should never be poured onto that crystallized, as it has been found that normal sirup mixed with crystallized sirup quickly hardens. Where bags are used they can be discarded for new ones. Crystallized sirup can be easily removed from cans by heating to boiling. (Fig. 16.) The cans should be repara-fined.

NUMBER OF CONTAINERS.

A container should be attached to each tree in orchards over run with ants. The ants colonize around the base of the trees where the food supply is plentiful, and in clean-cultivated orchards, such as are common in California, and are seldom found between the rows of trees. When food becomes scarce, movement from one tree to another is more common. One striking case of the restricted movement

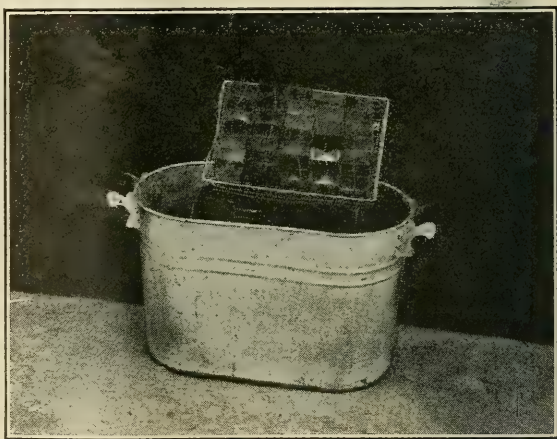


FIG. 16.—Cleaning crystallized sirup from container. Cans are arranged in trays and boiled in water, after which the contents are quickly removed by inverting the trays.

of ants in well-cultivated orchards was observed in an orchard during the spring of 1920. One row of trees near the center of the orchard was missed at the time of sirup distribution, and the first inspection showed the ants almost totally eradicated throughout the orchard with the exception of this one row, which continued to be heavily infested. During experimental work groups of trees in one side of an orchard have had the ants controlled through sirup distribution although the rows bordering these trees were little influenced. Orchards in which only part of the trees are attended by ants need sirup containers only on the infested trees. In California the plantings are for the most part from 70 to 100 trees to the acre.

COMPARATIVE COST OF TINS AND PARAFFINED BAGS.

The cost of ant sirup fluctuated greatly during the period of experimental work, 1917 to 1920, largely because of the changing price of sugar and honey. The cost of materials for each gallon of sirup in 1917 was \$0.61 compared to \$1.54 in 1920. The cost of the 2-ounce flat spice tins increased about 20 per cent, while paper bags increased over 35 per cent in price. The labor cost also materially increased. The following comparison is based on 1920 prices:

TABLE 2.—*Showing the comparative cost of poisoning ants when using tins and when using paraffined bags, season of 1920.*

Two-ounce flat spice tins.		One-fourth-pound paraffined bags.	
Ant sirup for 100 cans ¹	\$1. 83	Ant sirup for 100 bags ¹	\$1. 83
100 2-ounce spice tins.....	1. 75	100 $\frac{1}{4}$ -pound bags.....	. 15
1 pound paraffin.....	. 25	1 pound paraffin.....	. 25
100 2d. finishing nails.....	. 015	100 6-ounce tacks.....	. 025
LABOR. ²		LABOR. ²	
Punching and dipping 100 cans.....	1 $\frac{1}{2}$ hours.	Punching and dipping 100 bags.....	1 $\frac{1}{2}$ hours.
Filling and capping 100 cans.....	$\frac{1}{2}$ hour.	Filling and closing 100 bags.....	$\frac{1}{2}$ hour.
Distributing.....	1 hour.	Distributing.....	$\frac{1}{2}$ hour.
At \$0.39.....	3 hours. 1. 17	At \$0.39.....	2 $\frac{1}{2}$ hours. 1. 07
Total.....	5. 015	Total.....	3. 325
Total cost per can.....	. 05	Total cost per bag.....	. 03 $\frac{1}{2}$

¹ Based on 84 cans to the gallon at \$1.54 per gallon.

² This does not include time spent in preparing sirup.

INFLUENCE OF CONTAINERS ON FEEDING.

Although both paraffined paper sacks and tin cans have been used by the writers for approximately three years, no difference in feeding or rapidity of control attributable to the type of container was observed. It has been stated by some experienced in ant control that greater feeding and more rapid control are effected by the use of paraffined paper bags. An experiment to determine this point was started in 1920 and the results are presented herewith: Sirup

was put out on 46 trees in $\frac{1}{4}$ -pound paraffined bags and on 46 trees in 2-ounce paraffined spice tins. Frequent inspections were made of the feeding habits and careful attention paid to any apparent preference for either type of container. The experiment was conducted for two months and percentages figured showing the relative feeding habits. An average of 63 per cent of the bags were attended during the period, and an average of 62 per cent of the cans were fed upon. The ants showed no apparent preference for one type of container over the other. It has been observed that evaporation is more rapid in the bags than in the cans, hastening thickening of the sirup.

FACTORS INFLUENCING CONTROL.

The control of the Argentine ant under California conditions is very variable. In some cases control has been effected within one to two months and occasionally eradication within a like period. In others not even a noticeable reduction of ants has been accomplished within a much longer period. Inspection of containers in certain orchards has shown an occasional ant to feed for several weeks after distribution, while in other cases containers would be swarming with ants within a few hours after the sirup was placed within reach. As a general rule, however, the feeding is heaviest for the first few days when the sirup is fresh; after this the attractiveness is somewhat reduced.

WEATHER.

The weather, especially the temperature, appears to influence feeding greatly. During the hot summer months an arsenical sirup is less attractive than at any other time of the year, and control is slow, frequently unsatisfactory. The ants at this period are exceedingly active, and heavy streams have been known to pass up and down the trunk for weeks at a time, in some cases even right up against the container, without being influenced in the least by the proximity of the sirup. This extreme indifference to sirup is the exception rather than the rule. The maximum temperature at which ants actually slacken or stop activity has never been noted, but the senior writer has observed ants moving freely along the tree trunks at a temperature of 117° F., a degree of heat that proved destructive to many Diptera and Neuroptera. The writers have observed that the movement of ants becomes sluggish as the temperature of 50° F. is approached, and it is during these periods of low temperature that the sirup appears to prove most effective. The tendency of the ants is to cluster close together during the cool mornings in spring and autumn, especially in and about the crotch of the tree. If containers of sirup are present they prove a center of attraction and are frequently attended in large numbers.

FOOD SUPPLY.

Trees severely infested with mealybugs or other honeydew-exuding insects offer a favorable food supply for the Argentine ant. Control on such trees is difficult at any time of the year and usually not to be accomplished during the summer merely by the distribution of sirup, for the ants prefer their natural food to that furnished artificially. The only way to control the ants under such conditions is to remove the insects furnishing the natural food supply, prevent access of the ants to these insects, or else await the autumn or spring when the natural food becomes much reduced and the cold weather promotes feeding on the poisoned sirup. As an illustration of this condition the case of an orchard at Sierra Madre might be mentioned. On June 1, 100 bags of ant poison were distributed in one corner of the orchard, which at the time contained a few mealybugs. Within two months the ants on these trees had been brought under control. On August 1 poison bags were distributed throughout the rest (about 10 acres) of this ant-infested orchard, which was then severely infested with mealybugs. An inspection on October 19 showed no noticeable reduction of ants throughout that part covered by ant sirup in August. The infestation of mealybugs also continued to be severe. With the approach of cold weather and reduction of the numbers of mealybugs the ants fed greedily on the sirup, and by the following spring were practically under control.

On April 26, 1918, ant sirup was placed on 68 large orange trees at Pasadena severely infested with mealybugs. Forty-two of these trees were banded above the sirup cans to prevent the ants reaching the mealybugs, and the remaining 24 were left unbanded. An inspection on April 30 showed large numbers of ants attending the sirup on the banded trees, but not a single can on the unbanded trees was sought by the ants. The second plot was ultimately banded to compel feeding and accomplish control.

During the blossoming period ants are attracted to the nectar within the flowers and control is sometimes difficult, especially during a period of warm weather.

Thus, any attempt at control should give due consideration to the natural food supply of the pest.

Excellent results in complete ant eradication have been obtained in orchards heavily infested with the soft-brown scale and the black scale by following up the usual fall fumigation practice with ant control.

SEASON FOR CONTROL.

The spring and autumn, because of the temperature and food supply, are the periods when control or eradication is most quickly effected in southern California. When the ants break up their

winter colonies in the spring, their instinct to multiply leads to an aggressive search for food at a time when the supply is scarce. Consequently, they feed ravenously at this time on ant sirup when offered. It is also during the spring and autumn that the night temperature approaches 50° F., which reduces ant activity, causes the ants to congregate in or about tree crotches of the main limbs, and greatly increases feeding, particularly in the case of trees infested with honeydew-producing insects. During the hot summer months, when the temperature seldom drops to 50° F., ants are active both night and day, and where other food is available they are not greatly attracted by the poisoned sirup.

This temperature influence, and the further important consideration that scale control by fumigation is confined largely to the autumn months, make the fall and spring desirable periods for poisoning the Argentine ant. The writers recommend that control be started between the time ants first appear in the spring and July 1, or from the last of September until congregation into winter colonies takes place. The time of the appearance of ants in the spring varies from year to year, as well as from locality to locality. In 1916 ant activity started the last week in February, whereas in 1920 it was about the middle of April before the winter colonies began to break up. With the approach of cold weather, which normally sets in during December, ants disappear from the trees, although in a very open winter, as that of 1917, complete winter colonizing does not occur.

REAPPEARANCE OF OTHER ANTS FOLLOWING CONTROL OF THE ARGENTINE SPECIES.

It has been stated by Newell that the Argentine ant will not tolerate the presence of other species of ants within its domains. In southern California the commonest species of ant in citrus groves not entirely overrun with the Argentine ant is *Prenolepis imparis* Say. *Formica cinerea* Mayr, var. *pilicornis* Emery ranks second, and *Tapinoma sessile* Say, *Dorymyrmex pyramicus* Roger, and *Cremastogaster lineolata* Say, var. *californica* Emery are of lesser importance. Orchards long infested with Argentine ants are entirely freed of these other species. The reappearance of *Prenolepis imparis* closely following the eradication of the Argentine ant has often been noted, particularly during the autumn and early winter months. One striking instance occurred in 1918 at Pasadena, where ant control was started in April on 258 trees, 4 of which were frequented with *Prenolepis*. These four infestations of *Prenolepis* were eradicated, and the Argentines on the other trees were brought under control during the summer and totally eradicated during the month of November, with the exception of a few trees in one corner. On October 17 *Prenolepis* reappeared on 1 marginal tree and by Novem-

ber 15 had spread to 41. By the middle of December this ant had established colonies throughout the orchard, with the exception of the corner where the Argentine species still maintained a foothold. Several instances of like incursions, but in lesser degree, occurred in orchards at Upland in 1918 and at Alhambra in 1919.

RELATION OF BREEDING TO CONTROL.

The most rapid and conspicuous increase in numbers of ants is during the months of July, August, and September, and this is accounted for by the high mean temperatures prevailing during that period and the abundance of available food. High temperatures stimulate the queen to maximum egg production, and the life cycle of workers from egg to maturity under these most favorable weather conditions approaches four to five weeks, instead of two to four months, as during the coldest weather. Since the Argentine ant has been observed to slacken activity at temperatures below 60° F., it is apparent that during the spring and autumn not only does the egg production become greatly reduced, but the period of development is lengthened. Therefore, poison distributed during the spring and autumn should prove most effective.

During the hot summer months when all stages are present and the development is so swift the rapid destruction of all workers present at the time of sirup distribution would not clean up the infestation because additional workers would be daily emerging from the pupæ and these could care for the undeveloped larvæ. Eradication of the young during the summer by poisoning of workers is less likely at this time than during the period of slow development.

CONTROL ON MARGINAL TREES.

Ant eradication has been most difficult on the outside rows of orchards, particularly so when bordered by ditches or strips of uncultivated land. In clean-cultivated orchards, as stated elsewhere in this bulletin, there is little movement between trees, yet the marginal rows are commonly attended by ants breeding in the strips of bordering ground. If this adjacent territory is heavily colonized by ants, the latter will be attracted by sirup on these trees. The greatest difficulty has been experienced at times in eradicating ants from these trees, and ants have been eradicated from entire large orchards with the exception of outside trees. The difference in rapidity of eradication between the marginal two rows of trees and the rest of a 10-acre orchard by the sirup method is shown in figure 17. Orchards from which ants have been entirely eradicated one year have been known to have the outside two to three rows reinfested the following year from adjacent ant-sustaining territory. As a matter of precaution it is sometimes advisable to keep containers of sirup on the outside row

of trees even after ants have been eradicated from an orchard. Such action, if long continued, ultimately will result in reduction or control of the ants in the immediately adjoining strip of land and will act as a protection to the rest of the orchard. Particularly necessary is it to keep up the fight on house-lot property. The writers have totally eradicated ants from small city properties only to have incursions a short time later from the outside.

CLEAN CULTURE.

Ant eradication by the sirup method is difficult in uncultivated orchards or in orchards with rank vegetation beneath the trees. (Fig. 18.) Weeds and grass harbor plant-lice, scales, and other in-

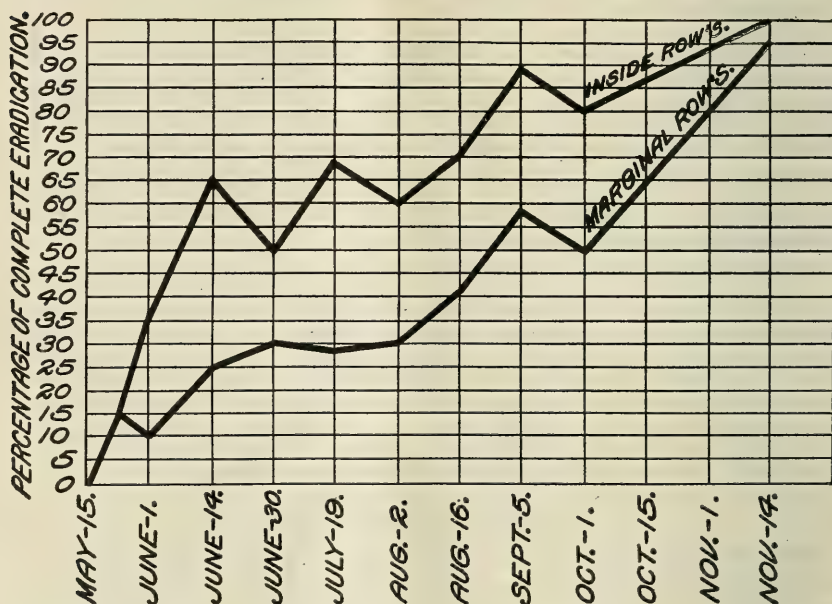


FIG. 17.—Comparative progress of ant eradication on marginal and inside rows of a 10-acre citrus orchard.

sects which furnish honeydew and distract the ants from the sirup. Such growth in contact with the branches offers avenues of travel distant from the poison. Clean culture should be practiced and, where possible, the lower branches pruned to prevent access to the tree except by the trunk. (Fig. 19.)

CONTROL ON HOUSE LOTS OR ABOUT BUILDINGS.

The control of ants on house lots or about buildings requires greater attention than does orchard work and furthermore is slower. Ground traps are advantageous in addition to the regular field containers. In order to effect rapid reduction of the pest, liberal distribution of containers has been found advisable. It has been the custom of the



FIG. 18.—A citrus orchard in which clean culture is not practiced. It is difficult to obtain ant control by the poisoned-sirup method on such property.



FIG. 19.—Citrus orchard showing clean cultivation, a condition necessary if rapid ant control by the use of the poisoned sirup is to be secured.

writers to hang a container on each tree or shrub about the property and to place several about the house along the foundation where trails of ants are found. Where ant-frequented property adjoins, it is well to distribute containers at the margin. They can be tacked in protected places on fences or to hedges. Ground traps should be placed

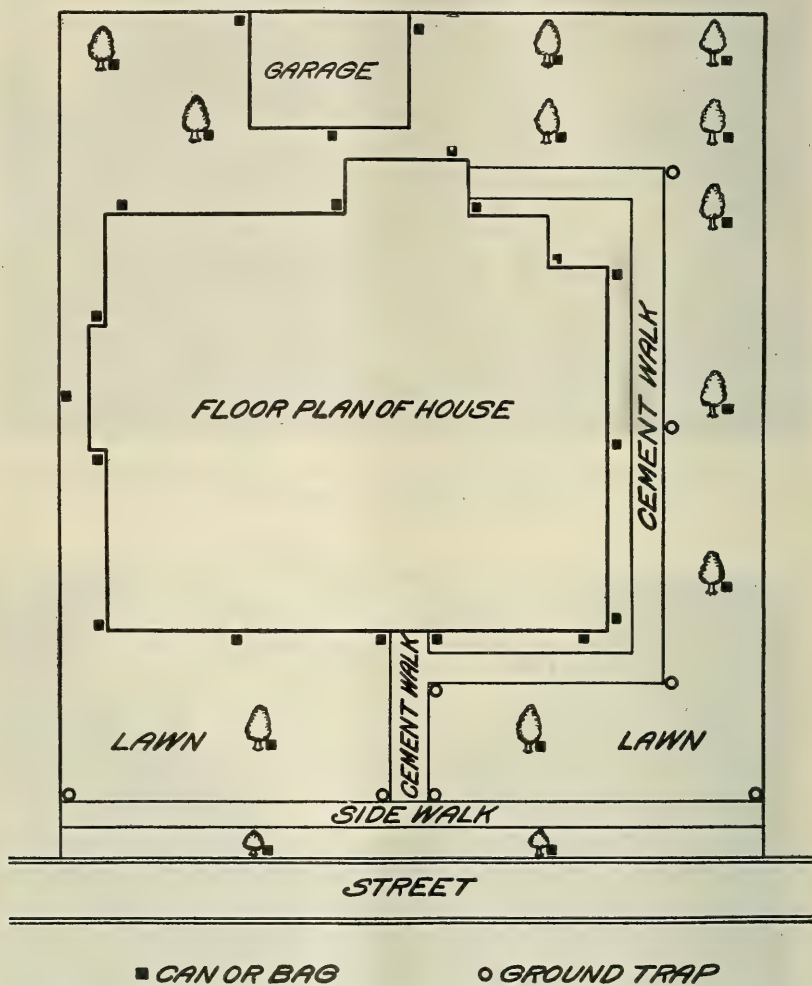


FIG. 20.—Diagram of residential property showing distribution of poisoned-sirup containers.

along sidewalks and about lawns where trails are located. A satisfactory distribution of containers on a 50 by 200 foot lot is shown in figure 20.

COMPREHENSIVE DEMONSTRATION OF CONTROL.

A campaign directed toward the control of the citrophilus mealybug was started at Upland in 1917, and it was soon discovered that the 600 infested acres were entirely overrun with the Argentine ant.

Therefore an effort to eliminate the ant was immediately started, and on August 28 ant poison prepared according to the original Barber formula was placed in paraffined paper bags on a 2-acre demonstration orchard, a bag to each tree. Within two weeks the effectiveness of the sirup was apparent, a reduction of fully 50 per cent being shown over the adjacent untreated trees. Within a month the ants were under control on most of the trees.

This very successful demonstration proved immediately convincing to orchardists in the neighborhood, and by the months of September and October the owners, representing 160 acres of infested orchards, had been induced to attempt ant control. During 1918 the territory covered was greatly extended and by the end of the year the treated territory had been brought up to 490 acres, or only 110 short of the entire mealybug-infested territory. These 110 acres were placed under control during the spring of 1919.

The methods which have been put into operation by the writers and are fully presented under demonstration orchard B were applied throughout the campaign. The original Barber poisoned sirup was used during 1917, but in 1918 the modified more dilute sirup was adopted and subsequently used exclusively. A very large amount of the poisoned sirup was prepared under the direction of the junior author or was supplied by qualified druggists. Spice tins were used very largely as containers.

The results of these very extensive control operations were entirely satisfactory. Total eradication of ants over a large acreage was accomplished during 1918. In the spring of 1919 a careful inspection was made of all the acreage on which control had been attempted, the results of which are shown in figure 21. At that time the ants had been entirely eradicated over approximately 450 acres, including the territory over which control was started in 1917. The entire area was under control by the spring of 1920.

The cost of control for the whole district averaged between 4 and 5 cents per tree.

SUMMARY.

An investigation of methods for control and eradication of the Argentine ant was started in 1915 and continued until 1920. The methods used included banding of trunks to prevent the access of the ant, trap nesting, repellents, and the use of poisoned sirup.

Of the various substances tried in banding, a mixture composed of 1 part of sulphur and 6 parts of commercial sticky tree-banding material proved most satisfactory. The careful attention necessary to keep the bands in a freshened condition, their high cost, and the ourstanding fact that the ants remained an everlasting menace, however, led to their discontinuance.

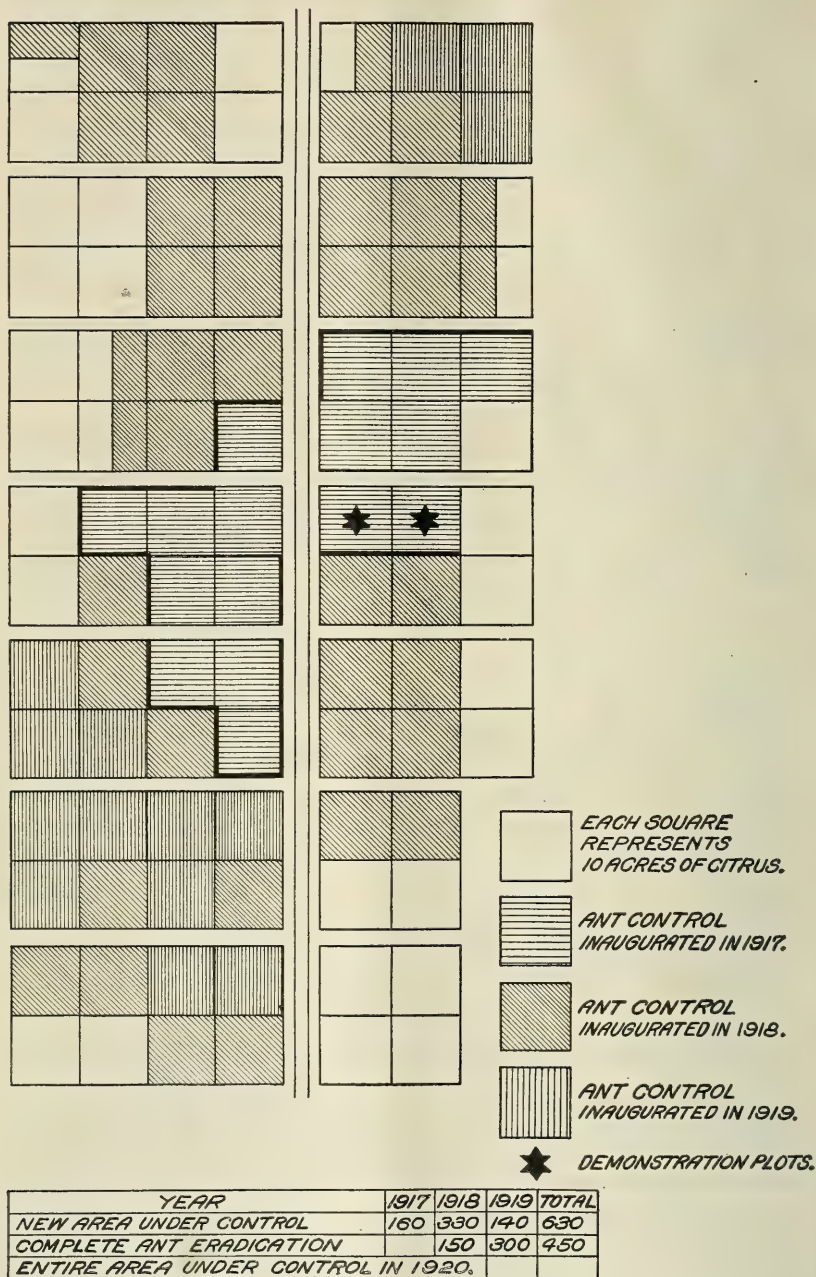


FIG. 21.—Diagram of the area under Argentine ant control at Upland, Calif., 1917-1919.

Trap nesting proved to be impractical under southern California conditions because of the light average rainfall and the excessive cost as compared with that of the use of a poisoned sirup.

Repellents, in the form of corrosive-sublimate bands and powders prepared from pyrethrum and sodium fluorid, were found to have a limited use about residences, apiaries, etc.

The most practical means of control was the complete eradication obtained by the use of an arsenical poisoned sirup. Numerous formulas were prepared and tried in large field experiments. Of these the original Barber formula proved effective, but was objectionable because of rapid crystallization. Various modified formulas were used and one finally adopted which contained all the ingredients of the Barber formula, somewhat reapportioned, and, in addition, the preservative benzoate of soda. The modified formula gives a much thinner sirup, one of greater stability, and also a considerably cheaper one. The arsenical poisoned sirups have been used in various parts of southern California on almost 3,000 acres of citrus with excellent results. Ants have been totally eradicated from many hundreds of acres with one or two applications. It is essential that the sirup be carefully and properly prepared.

Orchard control.—In orchard distribution approximately $1\frac{1}{2}$ ounces of sirup are placed in a 4-ounce spice tin with a few strands of excelsior, and such a tin is hung on the trunk or a main branch of each infested tree. Spring and autumn are the preferred periods for this work. Monthly inspection should be made and empty and removed containers refilled and replaced. The average cost per tree has been between 4 and 5 cents.

Control about residences.—This method has proved equally successful in eradicating the ants about residences. Much care should be given to bait each trail, at intervals of 10 to 15 feet, with either a spice tin or a ground trap.

The eradication of the Argentine ant has resulted in commercial control of mealybugs and the soft brown scale over a large area in the citrus districts of southern California.

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L. O. HOWARD, Chief



Washington, D. C.

PROFESSIONAL PAPER

August 25, 1921

THE EUROPEAN HORSE-RADISH WEBWORM.¹

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INTRODUCTION.

Horse-radish grown in the northern United States and in Canada is subject to attack by a medium-sized caterpillar known both as the purple-backed webworm and the horse-radish webworm. Like so many of our insect pests, this species is of foreign origin and gained entrance into this country many years ago, but until recent years it has not been known to spread materially. While favoring horse-radish, it is also known to attack turnip and cabbage, and after feeding on the lower surface of the leaves sometimes webs them together near the ground. When abundant it attacks the stalks, even down to the roots.

Prior to the year 1919, when this webworm was first discovered in injurious numbers in Virginia near the District of Columbia, reports of injurious occurrences were nearly all confined to the maritime Provinces of Canada, although attack had been noted occasionally in Massachusetts, New York, New Jersey, and Wisconsin. The insect has been known to occur in the District of Columbia for several years, but heretofore it has been somewhat of a rarity.

This species makes the third specific enemy of horse-radish inhabiting North America, the other two being the introduced horse-radish flea-beetle (8)^{2, 3} and the native horse-radish webworm (9).⁴

¹ *Evergestis straminealis* Hübner; order Lepidoptera, family Pyralidae.

² *Phyllotreta armoraciac* Koch.

³ Numbers in parentheses (Italic) refer to "Literature cited," page 10.

⁴ *Plutella armoracia* Busck.

Two other webworms affect horse-radish in the United States, both introduced from abroad, namely, the imported cabbage webworm (7)⁵ and the diamond-back moth (10).⁶

DESCRIPTION.

THE MOTH.

The moth of this species is rather bright ocher yellow and the forewings are traversed by two irregular lines dividing the wing into thirds of nearly equal width. Near the tip of the forewing is a conspicuous lighter spot and another larger rounded one near the middle of the anterior border. Directly outward from this latter there is an angular 8-shaped spot. The wing expanse is about 1 inch (25 mm.) and the length of the body a little less than half an inch (10 mm.). This moth resembles in general contour the related *E. rimosalis* Guen., but may be readily distinguished by the characters given and with the aid of the accompanying illustration (fig. 1). In some individuals the outer edge of the forewing is much darker than in others, darker even than in *E. rimosalis*.

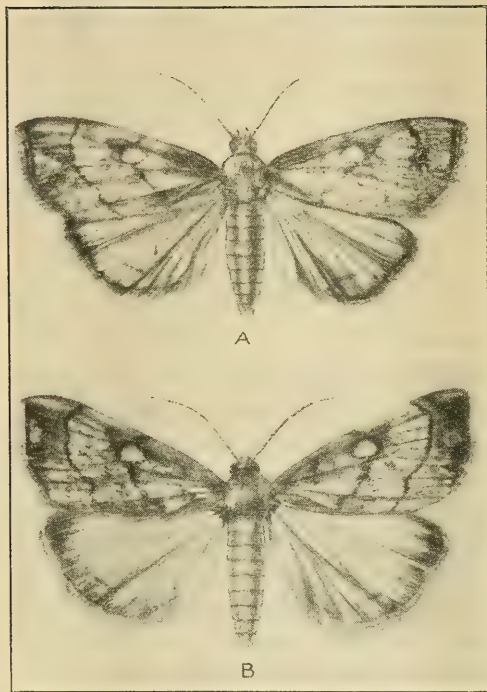


FIG. 1.—European horse-radish webworm (*Evergestis straminealis*): a, Moth, normal form; b, moth, dark form. Twice natural size.

The following more technical description is after Meyrick (5, p. 424):

Fore-wings pale ocherous-yellow, sprinkled with dark brown, veins posteriorly dark brown; lines dark fuscous, first angulated above middle, angularly indented above angle, second unevenly curved; an angularly 8-shaped discal spot, outlined with dark fuscous, touching angle of first line; a cloudy dark fuscous subterminal line, forming above middle a strong dark suffusion inclosing a pale terminal spot. Hindwings prismatic yellow-whitish; traces of a dark posterior line; termen narrowly dark fuscous.

⁵ *Hellula undalis* Fab.

⁶ *Plutella maculipennis* Curt.

THE EGG.

The eggs (fig. 2) are deposited in compact masses containing from half a dozen eggs to a score or more. Both the egg and the mass are difficult to describe, the individual egg being scarcely separate from the mass.

The individual egg is irregular oval, the mass being arranged more or less irregularly, as in the case of a honeycomb. The color is a little brighter green than the leaf on which it is deposited and each egg is surrounded by an irregular ring of yellow spots arranged in chains numbering about 12 to 18 to an egg. There is strong overlapping, so that an egg mass resembles, very imperfectly, a mass of fish scales. The surface is finely reticulate and divided into shining, minute, irregular areas much like the surface of leather. The diameter is about 0.8 mm.

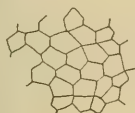


FIG. 2.—European horse-radish webworm: *a*, Egg mass *in situ* on leaf, three times natural size; *b*, section of surface of egg, highly magnified.

THE LARVA.

In the penultimate stage the larva (fig. 3) presents an appearance somewhat similar to the full-grown larva as regards the arrangement of the piliferous tubercles, but the form is more slender and the body tapers more at each end (the head being proportionately much smaller). The general color of the upper surface is purplish and has the peculiar appearance of being split through the middle, due to a wide pinkish longitudinal band separating the two parts between the rows of piliferous tubercles. The thoracic and anal plates are correspondingly smaller and faint yellowish brown.

THE FULL-GROWN LARVA.



FIG. 3.—European horse-radish webworm: Penultimate stage of larva. Much enlarged.

The full-grown larva (fig. 4) is elongate, cylindrical, about six times as long as wide, and tapers slightly toward each extremity, especially posteriorly. The general color is variable, generally either dull or shining dark slate gray above, sometimes faintly bluish. The lower surface is pale greenish yellow or yellowish, and the sides are marked with a narrow stigmatal line, orange about the spiracles and whitish or yellowish near the sutures. The head is shining jet black, faintly but distinctly separated, the delta-shaped middle portion longer than wide. The thoracic plate is piceous, the middle third or fourth paler, sometimes yellowish. The abdominal segments are without trace of transverse stripes; the piliferous tubercles are large and black: two pairs on the first two segments, the remainder arranged in groups of three, each side forming a triangle. The anal plate is small, dull pale brownish. The sides have

a row of substigmatal tubercles, one or two on each segment and another row midway between these and the legs; the legs are greenish or yellowish.

The length is 18 mm.; the width, 3 mm.

The larva has been described as purple, but the mature larva exhibits no evidence of this color in life. When preserved in alcohol there is a reddish and sometimes slightly purplish tinge.

The larva can be readily separated from that of *E. rimosalis* by the complete lack of transverse striation and by the black head.

When about to transform to pupa, the larva forms, usually at or near the surface of the ground, a substantial cocoon (fig. 5), which is evidently well coated on the exterior with a viscid substance to which particles of sand become at-

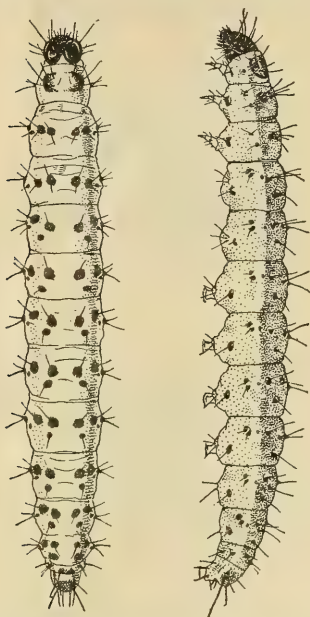


FIG. 4.—Full-grown larva of European horse-radish webworm: *a*, Dorsal view; *b*, lateral view. Four times natural size.

tached. These cocoons are large in comparison to the pupa and irregular short oval in shape.

THE PUPA.

The pupa (fig. 6) is of robust form with long wing cases

extending to the antepenultimate segment of the abdomen. It is widest below the middle across the wing cases and at its widest part is three-eighths as wide as long. The general color is brownish yellow, but the wing cases have a distinct greenish tinge. The eyes are large and black. The last abdominal segment is prolonged and unarmed.

The length is 8 mm.; the width, 3 mm.

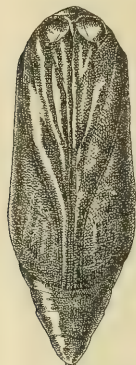


FIG. 6.—European horse-radish webworm: Pupa. Six times natural size.

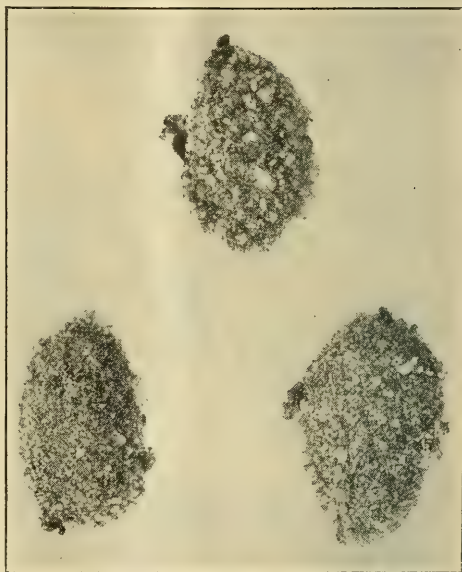


FIG. 5.—Cocoons of European horse-radish webworm. Much enlarged.

DISTRIBUTION.

Evergestis straminealis is native to the Old World, where it is found in Central Europe and in Great

Britain and Ireland. In Canada it has been reported from Cape Breton Island, Little Bras d'Or, Old Chelsea, Quebec, and Nova Scotia. In the United States it has been established for many years at Cambridge, Mass. Specimens are in the United States National Museum and it is noted as occurring in the following localities: Albany, Rochester, Kendall, N. Y.; Chester, N. J.; Cambridge and North Adams, Mass.; New Hampshire; northern Illinois; Madison, Wis.; Washington, D. C.; and Arlington, Va.

The known distribution is shown in the map (fig. 7).

NOTES OF OCCURRENCE AND HABITS.

The moth of this species was collected by the writer in September, 1898, at Washington, D. C., showing that it has evidently been established in this vicinity for several years, presumably feeding on horse-radish, though in small numbers, since it did not attract attention until 1919.

The records of the Bureau of Entomology show that the species was received July 27, 1903, from Dr. E. P. Felt, Albany, N. Y.

June 21, 1913, larvæ were observed attacking horse-radish at Chester, N. J., by H. O. Marsh. Larvæ under observation on June 30 burrowed into the soil and spun cocoons. The first of these transformed to pupa July 23, and the moth issued August 13, making the pupal period in this case 21 days.

June 14, 1914, specimens were received from Mr. Francis R. Foxcroft, with report that the larvæ were injuring turnip and radish at Cambridge, Mass., and that the leaves had been almost entirely devoured in that vicinity.

July 15, 1919, William H. White, Bureau of Entomology, observed larvæ on horse-radish at Arlington, Va., and later the writer observed this insect in the same locality.

Eggs which were deposited July 17, 1919, hatched July 24, and the larvæ from this lot, feeding on horse-radish leaves, began to transform to pupæ August 5. In this case the egg period was 7 days. The temperature was normal for the season, 64° to 91° F., and averaging 77° F.

By the third week of July, 1919, all moths from larvæ in confinement had issued from the cocoons; but another lot containing many

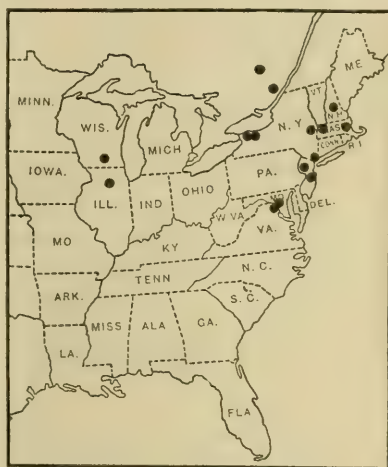


FIG. 7. Distribution of European horse-radish webworm.

individuals living in a rearing cage in the open descended into the earth and when pupal cases, which were not far from the surface of the earth, were examined much later, it was found that the larvæ were unchanged and that no moths had issued.

During October it was observed that larvæ were again infesting the same horse-radish patch where first discovered at Arlington, Va., and by October 17 considerable injury had been done to the foliage, quite as much showing at this time as that done by the harlequin cabbage bug during the season. Where the leaves were dead and dry and were more or less loosely matted together, the larvæ were invariably found; indeed, they infested the entire patch from one end to the other. Larvæ were rapidly growing to maturity at this time, feeding sparingly and sluggishly during the cool weather which prevailed when under observation in the field. Characteristic injury to the lower leaves as inflicted in midseason is shown in figure 8.

Larvæ feed in colonies at first, but with the period of approaching maturity they are soon to be found singly and well scattered throughout the field. Some few are protected by white silken webs joining two leaves together or by drawing a single leaf somewhat lightly at the middle near the midrib. The great majority, however, are freely exposed, although sheltered from the sun by overhanging foliage. They feed for the most part near the midribs and near the middle of the plant, seldom near the outer ends, which as the season advances become for the most part dead and dry.

From the hatching of the larva until its maturity the life history of the species is well told by Buckler (4) as follows:

The newly-hatched larva is green, and rather transparent, with a flattened black shining head and dark brown neck-plate, and on the body can just be discerned most minute black dots and hairs; after eating out little pits and channels from the cuticle, causing transparent blotches on the leaf for about five or six days and acquiring more colour, it becomes of a very pale watery-green as it lays up to moult.

After the first moult it eats holes quite through the leaf, and its ravages are very perceptible; its head is black, the back dark green, the belly pale watery-green, the sides of the shining neck-plate dark brown, while the middle of the plate is of the same green colour as that of the back, the wart-like spots are of the ground colour but have dark brown centres bearing single hairs, and a pale ring is at the base of each spot.

Soon after the second moult it is very dark on the back with a deep and subdued blackish olive-green colour, while the belly has a much lighter tint of the same, these are separated by a spiracular stripe of bright yellow, the head, the side margins of the neck-plate, and the warty spots on the upper surface are shining black, on each side of the back are two very fine and much interrupted series of white linear dots, less broken on the second segment to the end of the fourth than on the others, the warty spots on the ventral surface are of the ground-colour, having dark olive-brown centres.

Directly after the third moult and for a day or so the ground-colour of the larva appears perfectly black, which enhances the brilliancy [brilliance] of the

broken white lines and the yellow spiracular stripes, but by degrees, after it settles down to feed again and grow, the black skin expands and the ground-colour of the back becomes more and more green until it is again of a blackish olivaceous-green, when the length ranges from 13 to 16 mm.



FIG. 8.—Horse-radish leaf skeletonized by the European horse-radish webworm.

It now consumes a great quantity of food and the plump skin begins to shine a little; at the end of about ten days it attains full-growth.

HISTORY IN NORTH AMERICA.

The species was described by Hübner from Europe in 1792 (1) and must have been introduced into this country, probably with its favorite food plant, at an early date, since it came under the observation of Harris in 1841 (3, p. 322). In Harris's notebooks appear the following memoranda:

Oct. 30 and Nov. 1, 1841. Found on leaves of horse-radish.

They eat large holes out of leaves, leaving finally only the veins untouched. They live beneath the leaves, stretched out by the sides of the midrib. They creep regularly, not haltingly, and move pretty fast. When alarmed or disturbed they curl quickly, and lose their hold, and fall to the ground. . . . Found the same on turnip leaves, Oct. 20, 1844, their ravages very considerable.

This account includes a description and a reproduction of a sketch of the larva, which are omitted here. Walker's description appeared in 1859 (2, p. 756) and was based on specimens from the United States and Nova Scotia.

An account of this insect by William Buckler (4) appeared in 1882. Not knowing the insect's food plants, but judging that it would live on Cruciferae, he placed the eggs on different plants. In confinement the larvæ fed freely on *Barbarea vulgaris*, *Sinapis arvensis*, and *Cardamine amara*. Larvæ molted three times, as follows: The first molt occurred August 8 to 10, the second August 17 and 18, and the third August 24 to 27. By September 29 all were full-fed and were inclosed in cocoons of earth. The moths began to issue June 20 of the following year, continuing emergence up to July 27. Buckler describes the egg, stating that it hatched in 8 days, the newly hatched larva, the different molts, and the cocoon.

Many years after Harris's first account, Dr. James Fletcher (6, p. 231) furnished the second account, and writes in 1904 that occasional reports had been received at different times for 10 years of attack on cabbage and turnip in the maritime Provinces of Canada. The caterpillars were described as congregating on the crowns of turnips and eating cabbages into the roots as well as consuming the leaves. Whole fields of cabbage and turnip were destroyed at Cape Breton Island. The larvæ were described as starting under the leaves just out of the ground and mining their way up to the head, tunneling it hollow. Injury was also reported to cabbage in 1903 at Old Chelsea, Quebec, Canada, and an original description of the larva was included.

In 1918 a popular account of this species was published by Messrs. Crosby and Leonard (11, p. 19-20).

FOOD PLANTS.

Harris recorded *Evergestis straminealis* on horse-radish and turnip, and Fletcher noted attack on these plants and on cabbage in Canada.

In Europe the species has been recorded as feeding in confinement on wild plants of the genera *Barbarea*, *Sinapis*, and *Cardamine*.

NATURAL ENEMIES.

This species is apparently unusually free from natural enemies, judging by the experience gained from two years' study in the vicinity of the District of Columbia. A single parasite, *Bracon montrealensis* Morrison (Chttn. No. 6076⁰¹), determined by A. B. Gahan, was reared from the larva of this species September 6, 1919, at Arlington, Va.

CONTROL.

It is evident, considering the fact that only one natural enemy of this species is known, that little can be expected from natural agencies of control. The arsenates of lead and lime and arsenite of zinc will all undoubtedly operate against the larva with equal value when applied for other cabbage worms. Underspraying is necessary, because of the habit of the larva of feeding mostly in concealment near the base of the plant. Hand-picking, if carefully carried out, is also of value when the species does not occur in too large numbers, as in the case of the infestation at Arlington, Va.

In the occurrence of this species on horse-radish, it is more difficult of control than on cabbage and other annuals. On such crops fall and spring plowing and frequent cultivation would undoubtedly be of great service in destroying the insect in its pupal cases, which are usually at or near the surface of the ground. Plowing could not be practiced in beds of horse-radish, and here many of the pests would survive the winter unless a spray were applied, which should be done in case of severe infestation.

SUMMARY.

Horse-radish, and less often turnip and cabbage grown in the northern States, are subject to attack by the European horse-radish webworm (*Evergestis straminealis* Hübner), a greenish caterpillar with reddish or purplish tints, measuring, when full-grown, about three-fourths of an inch in length.

It feeds on the lower surface of the leaves, which it frequently webs together near the ground, and also attacks the stalks.

This insect came originally from Europe, and has recently made its appearance on horse-radish in Virginia. It is known to occur from New England westward to Wisconsin.

It passes the winter as a larva in an earth-covered pupal case near the surface of the ground and the moths appear some time in May. In Virginia the eggs hatch in 7 or 8 days, and the larvæ begin by

feeding on the leaves, when abundant attack the stalks, and attain full growth in about 3 weeks. They then transform to pupæ, and about 3 weeks later produce another brood of moths, making an approximate life cycle of 7 or 8 weeks, depending on temperature. At least two generations a year are produced in Virginia.

This webworm may be controlled by arsenicals and by hand-picking on horse-radish and, more readily on other crops, by fall and spring plowing and frequent cultivation.

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BULLETIN No. 967

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief



Washington, D. C.

PROFESSIONAL PAPER

October 14, 1921

RESULTS OF WORK ON BLISTER BEETLES IN
KANSAS.

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INTRODUCTION.

In the drier portions of western Kansas and adjoining States the insect fauna is particularly rich in blister beetles. Besides those of common occurrence elsewhere there are several species that are characteristic of the region. The native grasshoppers develop regularly in considerable numbers, thus insuring sustenance for some, at least, of the blister-beetle larvæ. The beetles feed on native legumes and other plants that root deeply and make some growth even when cultivated crops and shallow-rooted weeds die of drought.

The abundance of blister beetles in this region was noted by early entomologists, mostly systematists, who chanced through the western and southwestern United States: but it remained for Dr. C. V. Riley,

while entomologist of Missouri, to work out the first life histories of American species, and later as a member of the U. S. Entomological Commission to extend his researches in this line. Riley studied only species of general occurrence and only two of them to completion, yet he announced as his opinion that the life histories of other species would be found strictly parallel to these.

With the subsidence of outbreaks of the Rocky Mountain grasshopper (*Melanoplus spretus* Uhler), the Commission directed its attention to the more pressing problems of thickly settled portions of the country. The writer knows of no further study of the economic relations or biology of American species of this group.

The data on blister beetles that form the basis of this bulletin were collected, except as otherwise specified, since 1913. From March, 1913, to May, 1915, inclusive, the work was conducted at Garden City, Kans. From June, 1915, to June, 1917, inclusive, it was continued at Wichita, Kans. As the beetles do not occur there in sufficient numbers to supply the necessary material, work on control measures was dropped, and only such life-history work was conducted as was possible with material collected on infrequent trips at irregular intervals to western Kansas.

ECONOMIC IMPORTANCE.

There has been a tendency among entomologists to class the western species of blister beetles as beneficial. This arises from the fact that their larvæ feed on the eggs of grasshoppers, from the ravages of which the early agriculture of the plains region suffered immensely. However, the species of grasshopper responsible for a large share of the injury, and the one that stands to-day an insect boggy to those of limited entomological knowledge, has disappeared from the scenes of its former activity so completely that specimens of it are curiosities to the new generation of entomologists.

Only since the agricultural possibilities of the semiarid regions have been developed along diverse lines has it been possible to form a true estimate of the economic status of blister beetles. The presence of extensive acreages of sugar beet, alfalfa, beans, and peanuts has allowed them to exhibit to the full their propensity as crop destroyers. The cultivation of large areas and the close pasturage of a great deal more have also altered the flora and environment to such an extent that the former equilibrium of the insect fauna has been disturbed. Cultivation has insured a much more extensive food supply for grasshoppers, and they have become distributed accordingly; but much of this increase in the food of grasshoppers has not been accompanied by a corresponding increase in food suitable for the adult blister beetles. The latter have, therefore, been

unable to spread so widely. Pasturage or other disturbance incident to the agricultural use of the land has proved a greater detriment to the blister beetles than to the grasshoppers. Even in localities where blister beetles are most abundant repressive measures for grasshoppers have been found necessary. Also, where blister-beetle larvæ infest a large percentage of the grasshopper egg capsules, they must destroy many larvæ of the beefly *Anastoechus nitidulus* Fab., and of the hymenopterous egg parasite *Scelio monticola* Brues, neither of which is known to be injurious in any stage. The larvæ of the beefly destroy a great many more grasshopper eggs than the larvæ of the blister beetles, but are helpless against the latter when they enter the same egg capsules.

It is questionable whether blister-beetle larvæ have ever been sufficiently beneficial to offset the damage done by the adults. Certainly they are now relatively of much less value than formerly. The group, therefore, must be considered injurious and will become more so with continued agricultural development of the semi-arid sections.

INJURY TO CROPS.

Blister beetles may devour only the petals and pollen of the flowers. They usually do this on beans, peanuts, and locust trees, and largely on alfalfa. On Irish potatoes, sugar beets, and to a lesser extent on the Russian olive, however, they commonly defoliate the plant. In either case the actual injury to the crop depends on the stage of growth which the plants have reached. When they are near maturity the yield is lessened, but the crop is not a total loss. Unless drought prevails at the time of defoliation, sugar beets usually put forth new leaves and continue their growth, but the effect of defoliation is recorded in decreased tonnage or sugar content, or both. A defoliation of Irish potato is usually disastrous, as is also the destruction of the blossoms of beans and of peanuts.

FOOD PLANTS.

Leaf-feeding insects, like the blister beetles, could not become as numerous in the semiarid regions as they do without the presence of some hardy native plant upon which they can feed during drought. At Garden City, Kans., the beetles feed upon the blossoms of the sunflower (*Helianthus* spp.), the goldenrod (*Solidago* spp.), the leaves and flowers of the few-flowered psoralea or scurvy pea (*Psoralea tenuiflora*), and on other prairie legumes. They also feed extensively on an introduced weed, the ground burnut (*Tribulus terrestris*).

The cultivated plants which they attack most extensively are the Irish potato (*Solanum tuberosum*), the sugar and garden beets (*Beta*

vulgaris), alfalfa (*Medicago sativa*), the garden bean (*Phaseolus* spp.), the peanut (*Arachis hypogaea*), and sweet clover (*Melilotus alba*). The writer has not noticed them feeding much on other plants, but references to literature show that they attack a great variety of vegetation.

As the beetles emerge they begin feeding on such plants as they find near by. Later they are driven to cultivated plants, because drought has killed the weeds or because they need a more abundant and continuous food supply to support them in their gregarious habits.

CLASSIFICATION OF SPECIES STUDIED.

The blister beetles belong to the coleopterous family Meloidae, the members of which contain in their bodies a substance that blisters when extracted and applied to the skin. Both subfamilies, Meloinae and Cantharinae, are represented in these studies, though only one genus of Meloinae was identified. This was *Meloe*, about 30 specimens of an undetermined species of which were collected (Chhtn. No. 2507). All of these were found along a short piece of roadway which was flanked on one side by a field of wheat and on the other by a weedy prairie pasture. The species may have been only recently introduced in this locality, as it was but a few rods from the bank of a main irrigation ditch which comes directly from the Arkansas River. It was not to be found elsewhere at Garden City. Specimens were secured April 24, May 7, and May 19, 1914. On May 7 one pair was taken in copula, but no eggs were secured. The immature stages were not observed, nor were the beetles seen feeding except on the young Russian thistle.

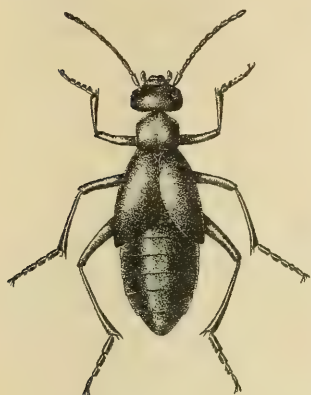


FIG. 1.—*Meloe afer*: Adult.
Enlarged.

DESCRIPTION OF MELOE SP.

ADULT.

Near *afer* Bland. or *barbarus* Lec. (Chhtn. No. 2507) : Length, 8 to 12.5 mm. ; width, 3 to 4 mm. ; elytra diverging, truncated, the body being widest across the abdomen near their tips ; color black ; rough and feebly shining. (Fig. 1.)

Of the subfamily Cantharinae, two tribes, Nemognathini and Cantharini, were represented.

The specimens of Nemognathini were identified as belonging to one genus and three species, *Nemognatha lurida* Lec., *N. bicolor* Lec., and *N. piezata* Fab. They were intermingling freely on blossoms of

the bull-thistle (*Cirsium lanceolatum*) and on account of their intergrading color patterns could easily have been referred to a single species. They were not observed in any injurious connection, and their immature stages were not found.

The tribe Cantharini was represented by three genera—*Macrobasis*, *Epicauta*, and *Cantharis*. To *Macrobasis* and *Epicauta* belong the injurious species occurring at Garden City, Kans., and they are treated at length in this paper. Of the genus *Cantharis* only one species was identified, *Cantharis reticulata* Say, of which a very few specimens were collected. They are sufficient for only a brief description.

DESCRIPTION OF *CANTHARIS RETICULATA* SAY.

ADULT.

Length, about 15 to 25 mm.; width, about 4.5 to 7 mm.; color black, except antennæ and legs, which are dark brown. Elytra irregularly ridged, hence the name; head, thorax, and abdomen pitted and sparsely haired; legs thickly haired. (Fig. 2.)

The adults were taken on the bush morning-glory (*Ipomoea leptophylla*), excepting one which was found on alfalfa.

Besides *Cantharis reticulata*, the tribe Cantharini is represented at Garden City by at least 15 species, of which four belong to the genus *Macrobasis* and 11 to *Epicauta*. For the purposes of this paper the generic and specific distinctions are sufficiently set forth by the key, which has been adapted from Horn with the assistance of H. S. Barber, of the United States National Museum.

KEY TO SPECIES OF *EPICAUTA* AND *MACROBASIS* COLLECTED AT GARDEN CITY, KANS.

- A. Second joint of antennæ at least half as long as third.....*Macrobasis*.
a. Black with posterior margins of abdominal segments gray.

M. segmentata Say.

- aa. Gray, yellowish, or brownish, unicolorous or with markings.

- b. Prothorax usually with two longitudinal black stripes; elytra usually concolorous, sometimes with submarginal black stripes; basal joints of antennæ brown (fig. 3).....*M. albida* Say.

- bb. Unicolorous.

- c. First joint of antennæ as long as or longer than the second and third together. In the male it reaches to the occiput, and the second is at least twice as long and twice as thick as the third.....*M. unicolor* Kirby.

- cc. First joint of antennæ similar in sexes, second joint shorter than third.....*M. immaculata* Say.

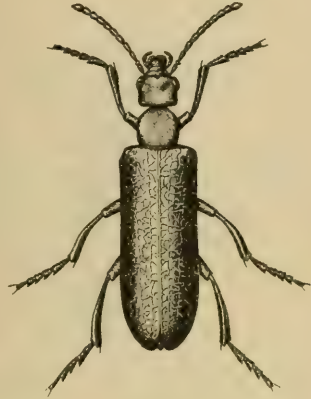


FIG. 2.—*Cantharis reticulata*:
Adult. Enlarged.

- AA. Second joint of antennæ less than half as long as third.....*Epicauta*.
 a. Antennal joints elongate, loosely united.
 b. Unicolorous.
 c. Gray or yellowish.....*E. cinerea* Forst.
 cc. Black.
 d. Large, 25 to 30 mm. long.....*E. corvina* Lec.
 dd. Less than 20 mm. long.
 e. Spurs of hind tibia stout, cylindrical; length 12 to 20 mm. (fig. 4).....*E. funebris* Horn.
 ee. Spurs of hind tibia slender, acute at tip and unlike, the outer spur being broader; length 8.5 to 14 mm.....*E. pennsylvanica* DeG.

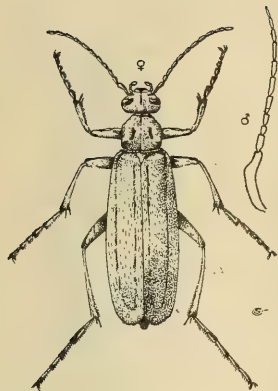


FIG. 3.—The two-spotted blister beetle (*Macrobasis albida*): Adult, striped variation. Enlarged.

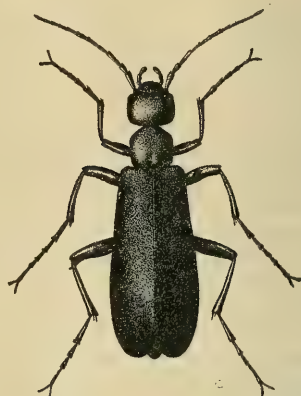


FIG. 4.—*Epicauta funebris*: Adult. Enlarged.

- bb. Variegated.
 c. Gray or yellowish with black markings.
 d. With three longitudinal black stripes on each elytron.....*E. lemniscata* Fab.
 dd. Spotted with black.
 e. Spots minute, scattering.....*E. maculata* Say.
 ee. Spots larger, crowded, sometimes coalescent.
 E. pardalis Lec.
 cc. Black, elytra and prothorax margined with gray, and median line of prothorax gray.....*E. marginata* Fab.
 aa. Antennal joints short, closely united.
 b. Pronotum with pair of bare, smooth, black areas; color reddish or grayish brown.....*E. callosa* Lec.
 bb. Pronotum unmarked.
 c. Surface of pronotum moderately shining under vestiture.....*E. ferruginea* Say.
 cc. Surface of pronotum opaque.....*E. sericans* Lec.

The only distinction between *Macrobasis* and *Epicauta* is in the relative length of the second segment of the antennæ (figs. 5, 6). In

Macrobasis it is at least half as long as the third and usually more. In *Epicauta* it is less than half as long as the third.

The four species of *Macrobasis* are easily distinguished, and no well-marked varieties in a species were observed. But there is great variation in the shade of color, especially in *M. immaculata*, and in the extent of the black submarginal stripes on the elytra in *M. albida*. These stripes next the outer and the inner



FIG. 6.—*Epicauta corvina*:
Antenna. Much enlarged.

margin of each elytron, if present, may extend so far as to unite at the distal end, forming a U that opens anteriorly. The black stripes on the prothorax may sometimes be lacking, but so rarely that it was not noted in the key.

As might be expected, since *Epicauta* is so much more richly represented than *Macrobasis*, it has greater variation within its species: also the separation of the species is much more difficult.

CHARACTER OF ADDITIONAL DATA ON MACROBASIS AND EPICAUTA.

In the rearing work eggs of several species were secured in confinement and hatched, giving authentic eggs and triungulins. No larvæ have been carried through the growing stages. Attempts to do so were thwarted by the high percentage of parasitism which existed among grasshopper egg-capsules that were collected for the purpose, and the writer was unable to secure eggs of grasshoppers by confining them. Coarctate larvæ were collected and kept under observation during the succeeding transformations. These yielded authentic material for the identification and description of the later stages.

In presenting the data relating to each genus the species on which they are most nearly complete will be considered first.

RESULTS OF WORK ON MACROBASIS.

DESCRIPTIVE.

MACROBASIS IMMACULATA SAY.

ADULT.

Macrobasis immaculata is among the largest blister beetles found in Kansas. A number taken at Garden City averaged 17.5 mm. long by 4.5 mm. wide. Blatchley gives the limits of its variation in length as 13 to 23 mm. Color gray to light reddish brown. According to Blatchley, the sexes are distinguished by the third antennal joint in the male being longer than the second, but in the female of only equal length or shorter.

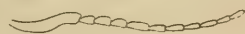


FIG. 5.—The spotless blister beetle (*Macrobasis immaculata*): Antenna of male. Much enlarged.

Egg.

Length, 1.5 mm.; width, 0.5 mm.; shape almost cylindrical, but tapering slightly toward the posterior end; color translucent yellowish white.

LARVA.

Triungulin (fig. 7).—Length, 2.7 mm.; width, 0.5 mm. through the head; shape elongate triangular, tapering gradually to the posterior end, which is bluntly rounded; color yellow or light brown, with lighter bands on the parts of segments that fold against one another when the body contracts in length; legs 3-jointed, strong; claws three in number (hence the name *triungulin*), slender, the two outer ones spinelike; eyes apparently only pigmented spots behind the antennæ on the anterior part of and near the outer margins of the head; mandibles flat, sickle-shaped, strong, with notched inner margins; antennæ apparently 3-jointed, the third joint divided with the dorsal portion the larger and bearing several spinose hairs; spiracles 9 in number and located above the lateral margins; armature of abdomen consisting of spinose hairs, about 10 in a transverse row near the posterior margin of each segment, and about 6 in a row nearer the anterior margin, those in each row so placed as to be in rows with corresponding hairs on the other abdominal segments; anal segment with two diverging hairs one-fourth to one-third length of body, projecting posteriorly from above its tip; hairs also regularly placed on thorax, head, and upper and outer surfaces of mandibles; legs with stiff hairs projecting perpendicularly on the femur but appressed on the tibia.

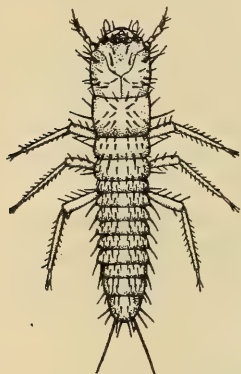


FIG. 7.—*Macrobasus immaculata*: Triungulin.

Carabidoid and scarabaeidoid larvæ.—Descriptions of these stages could not be secured from authentic specimens, as they were not reared. Collected larvæ that were thought to be in these stages were similar to those figured by Riley¹ for *Epicauta vittata*.

Coarctate larva (fig. 8).—Length, 11.5 to 13.5 mm.; width, 4.5 to 6.5 mm.; shape elongate hemispherical, resembling the half of a peanut kernel if the ends of the latter were bent toward its flat side and its edges thickened; color reddish brown; entirely inactive, the skin rigid; location of appendages shown by tubercular projections; limits of head shown by a constriction near the anterior end; segmentation of body plainly shown dorsally but less distinct ventrally; spiracles in shallow depressed line above the thickened edges.

Third larva.—Measurements difficult to make, though greater than for the coarctate larva; color white; shape robust, fleshy, and much wrinkled, larva

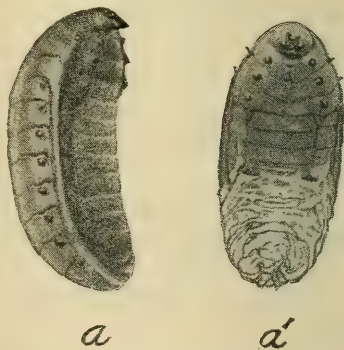


FIG. 8.—*Macrobasus immaculata*, coarctate larva: *a*, Lateral view; *a'*, ventral view. Enlarged.

¹ RILEY, C. V., PACKARD, A. S., and THOMAS, CYRUS. FIRST ANNUAL REPORT, U. S. Ent. Comm., Dept. Interior, U. S. Geol. Survey, 1877, pl. IV, figs. 4-7. 1878.

assuming a horseshoe shape when at rest; head horny, yellowish, with front almost vertical; mandibles brown, curved; antennae situated above the outer edges of the bases of the mandibles, apparently three-jointed, with two fleshy projections on the distal end of the third segment; first and second antennal segments with basal rings of brown and third segment brown for almost its entire length; eyes minute black spots above the bases of the antennae; sutures extending diagonally backward from the bases of the antennae, meeting at the median line above the middle of the front; labrum separated from the front by a brown suture; legs fleshy, jointed, the distal ends thickly studded with stiff brown spines; spiracles on second body segment and on fourth to eleventh, inclusive.

PUPA.

Length, about 17 mm.; width, about 7 mm. (measured from tip to tip transversely extended femora); color yellowish white with translucent appendages; head appressed on prothorax until front is almost parallel with body; femur and tibia of each leg folded together and extending forward, upward, and outward; tarsi extending posteriorly on the venter; antennae extending posteriorly dorsal to the anterior and middle legs; posterior margins of prothorax and abdominal segments bearing stiff, curved spines.

MACROBASIS UNICOLOR KIRBY.

ADULT.

Specimens of *Macrobasis unicolor* collected at Garden City, Kans., averaged about 13.6 mm. long and 3.4 mm. wide. Blatchley gives the limits of their variation in length as 8 to 15 mm. It is the slenderest of our species (fig. 9) and the sides are almost parallel; color ashy gray, sometimes with a yellowish cast, but more uniform than in any other species collected at Garden City, except the black ones.

EGG.

The eggs were not secured nor were the growing stages of the larvæ identified.

COARCTATE LARVA.

Five specimens vary in length from 10 to 12 mm., and in width from 4.5 to 5.5 mm. They are rather slender and of a yellowish brown color. In other ways they agree with the coarctate larvæ of *Macrobasis immaculata*.

THIRD LARVA.

Smaller and more slender than the corresponding stage in *M. immaculata*, but otherwise similar thereto.

PUPA.

The only specimen measured was 10 mm. long by 3 mm. wide. Though smaller and more slender it was otherwise similar to the pupa of *M. immaculata*.

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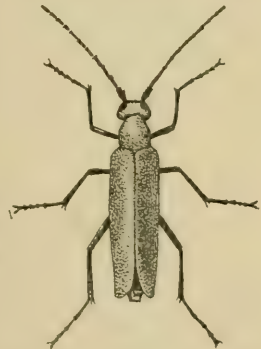


FIG. 9.—The ash-gray blister beetle (*Macrobasis unicolor*): Female beetle. Enlarged. (Chittenden.)

LIFE HISTORY AND HABITS.

MACROBASIS IMMACULATA SAY.

OVIPOSITION.

The female of *Macrobasis immaculata* deposits her eggs in small cavities (fig. 10) prepared in the soil wherever she may be feeding. In confinement no special preparation or arrangement could be observed. While on the staff of the Kansas Experiment Station the writer once observed oviposition in the field. The ovipositing female first came under observation about 3.30 p. m. She was busily engaged in excavating and continued thus as long as watched. The place was marked, and the writer returned at 6 o'clock to find her still at work. The next forenoon the spot where the beetle had worked had been

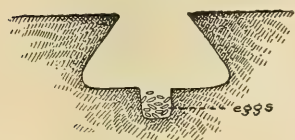


FIG. 10.—Cavity prepared for eggs by female of *Macrobasis immaculata*.

smoothed over, nothing remaining to indicate the location of the eggs except the identifying marks. Careful excavation revealed the outlines of a bell-shaped cavity in which the dirt had been replaced and loosely packed. In the center of the floor was a smaller cavity that contained a mass of several hundred eggs. The eggs were about $1\frac{1}{2}$ inches below the surface, and without definite arrangement or protective covering.

The earliest date at which eggs were secured in confinement was July 22 and the latest September 9.

INCUBATION.

As incubation proceeds the young larva soon becomes visible through the transparent shell. The body is translucent, distinctly segmented, and the head is closely appressed on the venter. The mouth parts extend backward below. The eyes are black, the tips of appendages brown, and the spiracles are ringed with brown. The hairs are closely pressed to the body, the two long ones on the anal segment being bent around so as to extend forward at the sides.

Eggs deposited July 22 hatched August 3, and some deposited July 24 hatched on August 5 and 6. The incubation period is thus from 12 to 14 days in length, but this becomes increased during cooler weather.

HABITS AND GROWTH OF LARVA.

The newly hatched larva soon becomes active. Where the beetles are numerous during the summer the little triangulins soon abound, and close observation will discover them hurrying about over the ground. They go into every crevice and under every clod and piece

of vegetable matter. Their mode of locating and entering grasshopper egg capsules has never been observed by the writer; but a few weeks later the large, plump, white scarabaeidoid larvæ and the reddish-brown coarctate larvæ have been found in capsules of grasshopper eggs. Probably a large percentage of the triungulins fail to find grasshopper eggs and perish from starvation. The fact that not more than one larva is ever found in a capsule indicates a further mortality through struggles between rival claimants for egg masses, since where the triungulins are so numerous it seems certain that more than one would enter each capsule of eggs.

All evidence that has been secured as to the rate of growth and the character of the accompanying transformations indicates that they are similar to and probably parallel with those described by Riley,² in the case of *Epicauta vittata*.

On becoming full grown the larvæ burrow away from the egg-capsules they have emptied, usually going much deeper, then turning toward the surface. There each larva forms an elliptical chamber at a slight angle with the perpendicular, stiffens out with the head uppermost, and sheds the old larval skin, which remains around the posterior portion of the abdomen. This leaves the elongate hemispherical coarctate larva standing almost vertically on end in the old exuvium and supported near the anterior end by the dorsal portion resting against the wall of the cell. The depth at which coarctate larvæ are found varies, being from 3 to 6 inches below the surface.

The coarctate larvæ have been found from late in summer until late the next spring. No scarabaeidoid larvæ large enough to belong to this species have been found during the winter or spring. This indicates that the species hibernates only in the coarctate larval stage.

After the spring's warmth penetrates to the coarctate larva the rigid skin splits along the anterior portion of the dorsal line. The third larva wriggles out and burrows toward the surface. The writer's earliest record of this transformation is dated May 28, but another record gives pupation on May 27, so it is safe to say that the third larvæ begin to appear in Kansas about May 20.

PUPATION.

After a few days' activity the third larva has approached to within 1 or 2 inches of the surface. Here it constructs an elongate cell at an angle with the horizontal of from 30° to 60°. It turns on its back therein (fig. 11) and begins transformation to the true pupa. The process requires several days, the exact time depend-

² RILEY, C. V., PACKARD A. S., and THOMAS, CYRUS. OP CIT., p. 299.

ing on the prevailing temperature. Pupæ have been secured beginning May 27 and continuing until August. Five that were handled in confinement between May 27 and July 24 had an average pupal period of 18 days.

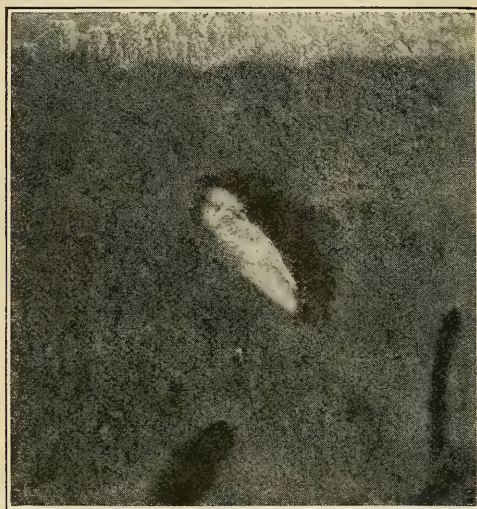


FIG. 11.—Pupa of blister beetle *in situ* in cell.

the pupal period, finally involving the legs and oral appendages. During its struggles the beetle rights itself and explores the narrow confines of its chamber. A thin, transparent, parchment-like membrane loosens on the surface of its body and is torn beyond recognition by the sharp tarsal claws. Adults from pupæ that have formed against the walls of glass containers have remained in the cells for several days after transformation before digging to the surface. Whether or not such is the case when light is excluded was not determined.

MACROBASIS UNICOLOR KIRBY.

The data secured on *Macrobasis unicolor* add nothing to the general account given for *Macrobasis immaculata*. The third larvæ have been collected by April 15, and eight specimens secured by that time had yielded the adults by May 30. The data on *M. unicolor* indicate that it, also, hibernates as coarctate larva.

RESULTS OF WORK ON EPICAUTA.

DESCRIPTIVE.

EPICAUTA MACULATA SAY.

ADULT.

Adult specimens of *Epicauta maculata* (fig. 12) varied from 10 mm. long by 2.25 mm. wide to 13 mm. long by 3.5 mm. wide, which makes it one of the

EMERGENCE OF ADULT.

As the time for emergence approaches, the tips of the appendages begin to darken. The coloration spreads gradually throughout the appendages and into the body. Several days before the emergence of the adults twitching movements begin in the tarsi. These become more vigorous toward the end of

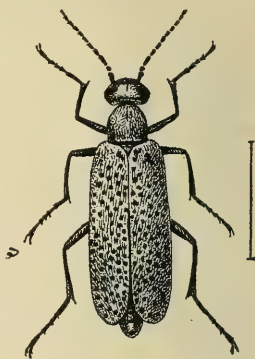


FIG. 12.—The spotted blister beetle (*Epicauta maculata*). Enlarged. (Chittenden.)

smallest of our common blister beetles. The color may be either light gray or yellowish, with scattered naked spots of the black background. The black spots vary both in size and location, being barely discernible on some beetles and at least 0.3 mm. in diameter on others.

EGG.

The egg of this species resembles that of *Macrobasis immaculata*, but is smaller.

LARVA.

Triungulin (fig. 13).—Length, about 1.25 mm.; width, about 0.4 mm.; widest in front of middle of head just behind eyes, from which point the head tapers posteriorly for the last half or more of its length. In this respect it agrees with triungulins of *Epicauta pennsylvanica* and *E. lemniscata*,³ but differs from Riley's figure of *E. vittata*.⁴ The head of the latter is parallel-sided, resembling *Macrobasis immaculata*, but differing in having a very short posterior portion or neck and in having the eyes located about the middle of the length of the head. In all triungulins examined by the writer the eyes are located much nearer the anterior portion of the head.

In other respects the triungulin of this species resembles that of *Macrobasis immaculata* (p. 8).

Active larva.—Neither the growing stages nor the third larva were recognized so they could be described.

Coarctate larva.—The writer's records show one coarctate larva that measured 9 mm. long by 4 mm. wide which yielded an adult of this species.

PUPA.

The pupa of this species was not described for lack of authentic material. It is similar in color and appearance to that of *Macrobasis immaculata*, but much smaller.

EPICAUTA CINEREA FORST.

ADULT.

Length of adult *Epicauta cinerea* (fig. 14), from 8 to 17 mm.; width, 1.75 to 4 mm.; shape slender, with sides of elytra almost parallel; color, bluish to light or yellowish gray.

EGG AND ACTIVE LARVA.

Neither the egg nor any of the active larval stages of this species were secured for descriptive purposes.

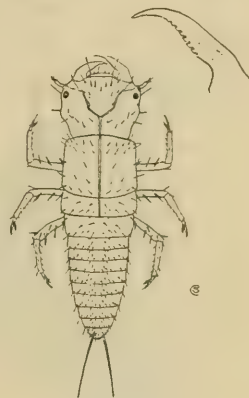


FIG. 13.—*Epicauta maculata*: Triungulin. Enlarged.

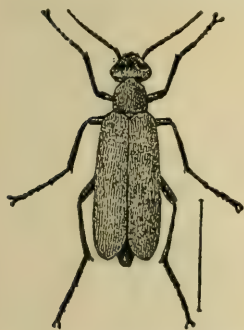


FIG. 14.—*Epicauta cinerea*: Adult. (Chittenden.)

³ Triungulins of this species were kindly furnished by Mr. Thos. H. Jones of the Bureau of Entomology.

⁴ RILEY, C. V., PACKARD, A. S., and THOMAS, CYRUS, op. cit., Pl. IV, fig. 2.

COARCTATE LARVA.

Length of coarctate larva (fig. 15), 7.45 mm.; width, 4.08 mm.; 28 specimens varied in length from 6.25 to 9 mm. and in width from 3.25 to 5 mm. Shape much more robust than that of the coarctate larva of any other species thus far

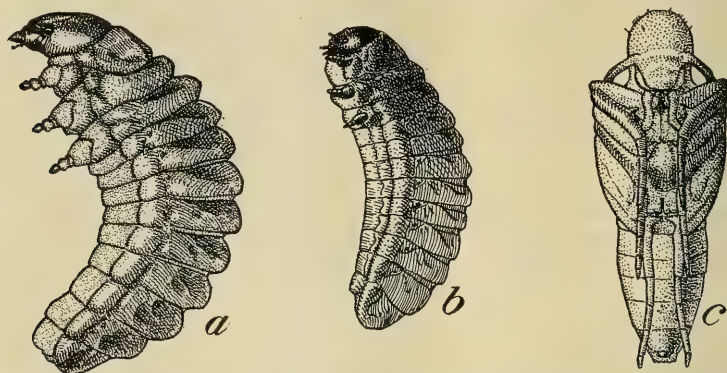


FIG. 15.—The gray blister beetle (*Epicauta cinerea*): a, Scarabaeidoid larva; b, third larva; c, pupa.

secured, being almost straight longitudinally on the venter and without the angular lateral ridges, thus leaving them almost circular in abdominal cross section; color a rich reddish brown, darker than any other species with which the writer has worked.

PUPA.

The single pupa (fig. 16, c) of this species which was measured had a length of 12 mm.

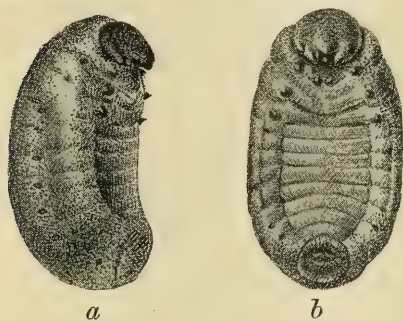


FIG. 16.—*Epicauta cinerea*: a, Coarctate larva, lateral view; b, coarctate larva, ventral view.

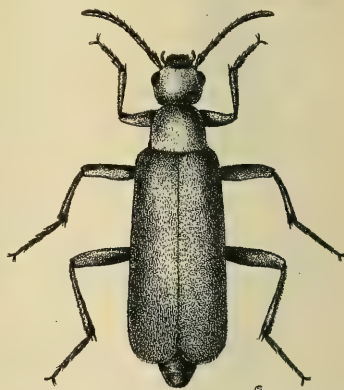


FIG. 17.—*Epicauta sericans*: Adult. Enlarged.

and a width of 4 mm. In shape, color, and general appearance it resembles the pupa of *Macrobasis immaculata*, but is not so large.

EPICAUTA SERICANS LEC.

ADULT.

Of 29 adult specimens of *Epicauta sericans* (fig. 17) the variation in length was from 9.5 to 13 mm., with an average of 10.8 mm.; color, light reddish brown through yellow and gray to almost silvery; antennae reaching to the elytra, the segments except the second being nearly as broad as long. The second segment is nearly twice as long as thick; sides of elytra nearly parallel.

EGG AND YOUNG LARVA.

The egg has not been secured or the growing stages of the larva recognized.

COARCTATE LARVA.

The average of 10 coarctate larvæ was 6.875 mm. in length by 3.8 mm. in width. They are reddish brown, but not so dark as those of *E. cinerea*, and the lateral ridges are present and distinctly angular.

THIRD LARVA.

The third larvæ are 7 to 8 mm. long by 2.5 to 3.5 mm. wide. In shape, color, and general appearance they resemble those of *Macrobasis immaculata*.

PUPA.

A description of the pupa has never been secured.

EPICAUTA PENNSYLVANICA DE G.

ADULT.

Epicauta pennsylvanica (fig. 18) is the smallest of the black blister beetles that occur in Kansas. Of 18 specimens, the length varied from 8.5 to 14 mm., averaging 10.3 mm., and the width from 2 to 4 mm., averaging 2.88 mm.; shape rather slender; color dull black.

EGG.

The egg resembles that of *Macrobasis immaculata*, but is much smaller.

TRIUNGULIN LARVA.

Length of triungulin larva (fig. 19) about 1.3 mm.; width about 0.3 mm., widest through the head about midway of its length, which is just behind the eyes, and tapering to the prothorax, into which it telescopes slightly; color, brownish yellow, translucent. In shape and general appearance it resembles the triungulin of *Macrobasis immaculata*.

None of the other larval stages have been secured, even the coarctate larva of this species having escaped recognition.

LIFE HISTORY AND HABITS.

EPICAUTA MACULATA SAY.

OVIPOSITION.

While on the staff of the Kansas Experiment Station the writer observed oviposition by a female of *Epicauta maculata*, as well as by a female of *Macrobasis immaculata*. Both were working at the same time, being discovered only a few yards apart in the edge of a field. The process was identical with both females, lasting from before 3.30 p. m. until after 6 p. m., as described under *M. immaculata*. The cavities to receive the eggs were made exactly alike—bell-shaped, with the flaring end down and the eggs reposing in a further depression at the center of the bottom of the bell; but the cavity made by *E. maculata* was only about 1 inch

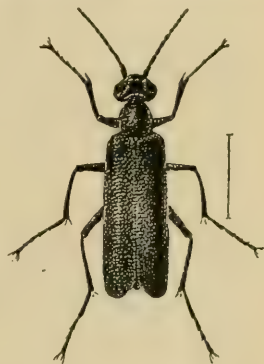


FIG. 18.—The black blister beetle (*Epicauta pennsylvanica*): Adult. Enlarged. (Chittenden.)

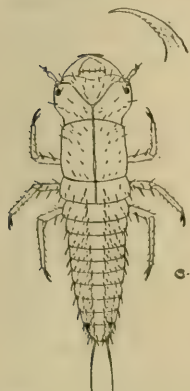


FIG. 19.—*Epicauta pennsylvanica*: Triungulin. Enlarged.

deep, as compared with $1\frac{1}{2}$ inches for the other. Several hundred eggs were in each nest.

In confinement eggs have been secured from July 27 to September 22. Confined females lose their instinct for careful oviposition, placing their eggs under a clod or leaf, or scattering them about on the surface without covering.

INCUBATION.

Incubation proceeds as described for *Macrobasis immaculata*. Eggs secured July 31 hatched August 18, and others deposited August 1 hatched August 22, giving an incubation period of from 18 to 21 days.

HABITS AND GROWTH OF LARVA.

The newly hatched larvæ soon become active. Their activities parallel those described for the triungulin of *Macrobasis immaculata*.

The coarctate larvæ are found near the surface, being but little deeper than the lower ends of the grasshopper egg capsules. Many are taken directly from the capsules. In confinement one third-stage larva appeared on May 6, the pupa was fully formed on May 12, and the adult came forth on May 25. The adults appear in numbers earlier than those of any other species of Cantharini taken in this region, this fact being corroborated by field observations. Since eggs were secured on September 27 it is evident that the adults occur throughout the summer.

EPICAUTA CINEREA FORST.

Oviposition by *Epicauta cinerea* has never been observed, nor have the habits of the larvæ preceding the coarctate been studied.

The coarctate larvæ have been collected at all seasons of the year and wherever grasshopper eggs are to be found. They occur from 2 to 5 inches below the surface in nearly upright cells, in which the larvæ are disposed as described for *Macrobasis immaculata*. The earliest date at which third larvæ have been collected was between April 12 and April 16. They are frequently found during the last week in May.

According to the writer's records the earliest pupation in confinement occurred May 8; but an adult for which the pupation was not recorded emerged on the same date, thus indicating pupation at least 10 days earlier. Other transformations follow rapidly and continue through the summer. From the dates recorded for the transformation of this species it would seem that its appearance in the field should precede that of *Epicauta maculata*, which, as stated above, is the earliest to appear of the Cantharini of this region. The apparent contradiction is reconciled by the occurrence of most of the coarctate larvæ at greater depths than those of *E. maculata*,

which prevents the reception of sufficient heat to start activity early in the season. Only those individuals of *E. cinerea* that are near the surface appear with the main brood of *E. maculata*.

EPICAUTA SERICANS LEC.

Adults of *Epicauta sericans* have been collected from June 6 to September 11. They are commonly found feeding in flowers on many kinds of plants, often being taken on sunflower (*Helianthus* spp.), other Compositæ, the scurvy pea (*Psoralea tenuiflora*), alfalfa, peanuts, and other cultivated legumes.

The eggs have not been secured or the growing stages recognized. The coarctate larvæ have been collected during the fall, winter, and spring, and emergence begins early in June. For these reasons this species is believed to develop normally one generation annually, hibernating as coarctate larva; but instances of retarded development have occurred, and these are considered under the proper heading.

EPICAUTA PENNSYLVANICA DE G.

The adults of the small black blister beetle have been collected at Garden City, Kans., from August 17 to November 11. At the latter date about half the adults had died, and the remainder were so stiff from cold that they could not cling to vegetation. They were first found on blossoms of the goldenrod (*Solidago* spp.), but later fed on the blossoms of the many-flowered aster (*Aster multiflora*), alfalfa, and a few other plants. Eggs were not found in the field, but were secured from adults confined on earth in a battery jar. On October 20 a cluster of 363 was deposited about half an inch below the surface. The eggs hatched on November 15, which was too late for development to proceed. This agrees with Riley's statement⁵ that the species evidently hibernates as the triungulin.

IRREGULAR DEVELOPMENT.

During the progress of these investigations some marked variations were observed in the time required for development. Of active, grown larvæ collected at Garden City, Kans., during the period from April 12 to 16, 1916, three transformed to coarctate larvæ of *Epicauta cinerea* by May 7. When examined again on May 29 they were found dead as third larvæ, having perished from lack of moisture. Under the circumstances it is impossible to say whether these specimens were mature scarabæidoid or the third larvæ when collected. Most specimens of *Epicauta cinerea* that have

⁵ RILEY, C. V., PACKARD A. S., and THOMAS, CYRUS. Op cit., p. 301.

been reared came from coarctate larvæ that were collected during the fall and winter.

Seven mature coarctate larvæ of one type, collected during the winter of 1913-14 were placed on soil in a perforated tin box. During the summer the box was buried in the insectary at a depth of about 2 inches and forgotten. The writer chanced upon it again November 25, 1914, finding in it six coarctate larvæ, one dead third larva, and seven cast coarctate skins. Only one explanation is possible. The coarctate larvæ all transformed to the third larvæ, and six of them reverted to the coarctate condition again. The seventh perished. On May 30, 1915, the six coarctate larvæ were separated into two lots of three each. One lot was placed in dry earth, the other in damp earth. The former showed no signs of activity. Of those in moist earth, one had decayed by July 2, another had transformed to third larva, and the third specimen remained unchanged and apparently healthy. The third larva continued its transformations, and on July 24 yielded an adult of *Epicauta sericans*. The four unchanged coarctate larvæ were stored in dry soil until the spring of 1916. Upon being moistened they decayed at once.

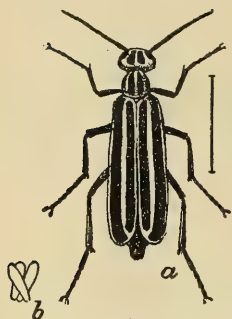


FIG. 20.—Striped blister beetle (*Epicauta vittata*): a, Female beetle; b, eggs. Enlarged. (Chittenden.)

A coarctate larva obtained during the winter of 1913-14 did not yield the adult until July 7, 1915. This proved to be *Macrobasis immaculata*.

Riley⁶ reports cases of retarded development in *Epicauta vittata* (figs. 20, 21). From the same batch of eggs he had beetles mature in one, two, and three years. Regarding one which required three years he wrote as follows:

In this case the individual, though submitted to exactly the same conditions as the other specimens, which had simultaneously hatched with it—but which went through all their transformations within either one or two years—remained dormant for nearly three years, with their repeated changes of season and temperature. With the exception of the first winter, when it was kept indoors without freezing and when development should have been presumably hastened, the specimen was kept in a tin box buried the proper distance beneath the ground out of doors, so as to be as nearly as possible under natural conditions.

Continuing the discussion of retarded development, he says:

In the case of our blister-beetles, depending as they do on locust eggs, and especially in the case of those which feed particularly on the eggs of migratory species, it is not difficult to perceive how this trait may prove serviceable to the species possessing it. Migratory locusts occur in immense numbers in some

⁶ RILEY, C. V., PACKARD, A. S., and THOMAS, CYRUS. SECOND REPORT, U. S. Ent. Comm. Dept. Interior, 1878 and 1879, pp. 260-261. 1880.

particular part of the country at irregular intervals, and there are periods or years of absolute immunity from their presence in the same regions. The young blister-beetles that hatch the year following the advent of the locusts in immense numbers may frequently find few or no locust eggs upon which to prey, and the great bulk of them would, as a consequence, perish; while the young from such exceptional individuals as should not develop till two, three, or more years after a locust invasion might stand a much better chance of finding appropriate food and of thus perpetuating the species. In this case and in most other cases of retarded development with which we are familiar, the exceptional retardation may and does become a benefit to the species, enabling it to bridge over periods of adversity. And we can see how, by the preservation of such favored individuals, the habit of irregular development may have become fixed in the species as a consequence of surrounding conditions and circumstances which render it advantageous.

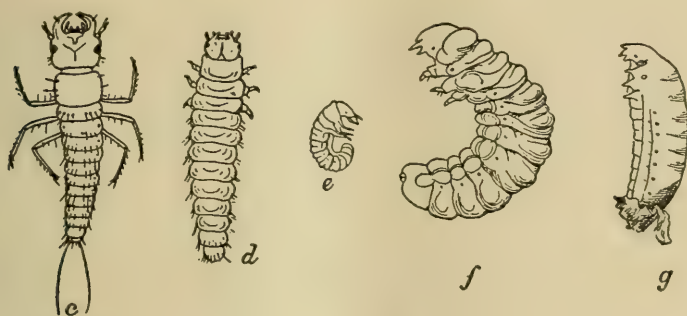


FIG. 21.—Striped blister beetle (*Epicauta vittata*): *c*, Triungulin larva; *d*, second or caraboid stage; *e*, same as *d*, doubled up as in pod; *f*, scaraboid stage; *g*, coarctate larva. All except *e* enlarged. (After Riley.)

In these two paragraphs Riley points out the tendency to irregular development which is exhibited in blister beetles, and the benefit which it undoubtedly is to the species. He discusses the irregularity as a tendency which is already acquired, though indicating its origin "as a consequence of surrounding conditions and circumstances." Whether he believed that irregular development could be induced in individuals by subjecting them to certain conditions he does not state.

During retarded development the additional time involved is spent in the coarctate larva stage. Low temperature inhibits development in any stage, but in the other stages activity is resumed with increased temperature. The hardy triungulin can survive for two or three weeks without food, but Riley reports⁷ that the first molt is usually experienced about the eighth day after the first taking of food, indicating that normal development begins with reception of nourishment. Entering an egg-capsule automatically limits the food a

⁷ RILEY, C. V., PACKARD, A. S., and THOMAS, CYRUS. FIRST ANNUAL REPORT U. S. Ent. Comm. Dept. Interior, U. S. Geol. Survey, 1877, p. 299. 1878.

triungulin can secure. If the eggs in a capsule fall short of the minimum requirement to carry the larva to maturity it perishes; if they exceed this minimum the difference is registered by the size of the beetle which develops. Consequently, in a given species there is great variation in size of the adults. The third larva is injuriously affected by insufficient or excessive soil moisture; however, the variation or limits in which it is safe are commonly prevalent in semiarid regions during spring and early summer. The pupæ are exceedingly sensitive, being injuriously affected by excessive soil moisture, handling, high temperature, or a soil rich in humus. Even prolonged high humidity injures them. Many on which a little earth dropped or that are exposed during an examination gradually turn dark and decay.

The coarctate larvæ, on the other hand, are resistant to handling, to exposure, to drying, or to any soil disturbance that does not crush them. They have even become overgrown by saprophytic soil fungus while in storage without loss of vitality. Excessive soil moisture, however, or continued high humidity, such as is necessary to produce conditions that favor the development of fungus, is usually detrimental. The position of the coarctate larvæ in the soil facilitates drainage, standing, as they do, on end in the old exuvium and touching the soil only in the dorsal region of the prothorax. Treatment to which they were submitted by the writer also demonstrated their ability to withstand extreme exposure and drying. Coarctate larvæ that remained for months in open containers without soil, in open containers on dry soil, and buried in pulverized dry soil have transformed shortly after being placed in moist soil.

When coarctate larvæ are very dry during the spring and early summer the rigid skin often splits immediately if water is thrown directly upon it, the larvæ emerging within a few minutes. Such dry coarctate larvæ also soon transform when placed on moist earth.

Coarctate larvæ that are kept dry during the spring and summer may or may not give forth the third larvæ when moistened in the fall. The instance cited of seven that were buried and forgotten and later found to have become third larvæ, six of which reverted to the coarctate stage, illustrates another mode of behavior of such specimens. During the time they were buried the insectary was flooded by run-off irrigation water from an adjacent field. The floor was barely covered by water and dried quickly, especially in the end where the box was buried. It is possible that enough water penetrated the box to initiate development, but not to complete it. The six larvæ that resumed the coarctate stage did so as a protective measure, or else the coming of cold weather caused this resumption. The writer attributes their reversion to one of these alternatives. Granting the correctness of these deductions, it indicates a more

complete adjustment to the semiarid conditions under which they thrive best than anything in Riley's writings that have come before the writer.⁸

An attempt will be made to apply these conclusions to field conditions as found in western Kansas: The rainfall is most abundant in spring; it gradually decreases through the summer, but increases again toward fall. The coarctate larvæ that receive sufficient moisture transform as soon as the temperature becomes favorable, and usually are able to complete their life history before the moisture becomes deficient. If for any reason—lack of rainfall, impervious soil, or deflection of rainfall by sheltering vegetation—the soil moisture is deficient, the coarctate larvæ remain dormant. If, after their appearance, the third larvæ find insufficient moisture they revert to the coarctate stage, and they may behave similarly if low temperature occurs. It is not known how long coarctate larvæ can remain dry in undisturbed cells without impairment of their vitality.

The preceding discussion of the environmental factors responsible for the phenomenon of irregular development in blister beetles is intended not only to present the author's interpretation of his data, but to direct attention to what he believes is a fertile field for research on the factors influencing insect development. The incompleteness of the data will insure the reception of this paper as a report of progress of work done during this period with the available time and material, instead of as a definite statement of results and conclusions.

CONTROL MEASURES.

While the writer was engaged in the work on life history and habits of blister beetles, tests were made of remedies whenever an opportunity occurred. The work on remedies may be considered under two heads: (1) Effect of arsenicals, contact insecticides, and repellents; and (2) control measures in infested fields.

EFFECT OF ARSENICALS, CONTACT INSECTICIDES, AND REPELLENTS.

ARSENICALS.

The widely prevalent idea that arsenicals are ineffective against blister beetles was left in doubt in the earlier tests of the poisons by the writer; the beetles would disappear, leaving but few dead ones visible. In order to learn definitely whether the beetles were killed by the poisons single beet plants were sprayed with each kind and beetles confined thereon in cages, 10 beetles being placed in each cage. The experiment was conducted three times during July, 1913, and the data are given in Tables 1, 2, and 3. The kind of poison

⁸ The writer has read only the reports of the U. S. Entomological Commission.

used is indicated at the heads of the columns, with its strength in pounds to so many gallons of water. With Paris green an equal quantity of quicklime was used.

TABLE 1.—*First experiment in the use of arsenicals, contact insecticides, and repellents against blister beetles; begun June 30, 1913.*

Date.	Number of beetles dead after spraying with—			
	Paris green, 1-1-25.	Zinc arsenite, 1-20.	Lead arsenate, 1-12½.	Bordeaux mixture, 4-4-50.
July 1..	0	0	0	0
2..	6	3	0	0
3..	10	8	0	0
4..	-----	10	0	0
5..	-----	-----	0	0
7..	-----	-----	5	1

When the experiment was discontinued the beet sprayed with Bordeaux mixture was defoliated with only one beetle dead, and the one sprayed with lead arsenate was badly damaged with only five of the beetles dead. Lead arsenate made such a poor showing that its strength was doubled in the second experiment.

TABLE 2.—*Second experiment in the use of arsenicals, contact insecticides, and repellents against blister beetles; begun July 7, 1913.*

Date.	Number of beetles dead after spraying with—			
	Paris green, 1-1-25.	Zinc arsenite, 1-20.	Lead arsenate, 1-6½.	Bordeaux mixture, 4-4-50.
July 8.	0	0	0	0
9.	3	10	2	0
10.	10	-----	8	0
11.	-----	-----	10	3
12.	-----	-----	-----	5

The beets sprayed with Bordeaux were again badly defoliated, but the increased strength of lead arsenate prevented much damage.

TABLE 3.—*Third experiment in the use of arsenicals, contact insecticides, and repellents against blister beetles; begun July 22, 1913.*

Date.	Number of beetles dead after spraying with—			
	Paris green, 1-1-25.	Zinc arsenite, 1-20.	Lead arsenate, 1-10.	Bordeaux mixture, 4-4-50.
July 24.	1	0	1	0
25.	3	2	1	2
26.	7	5	2	2
28.	10	7	4	7
29.	-----	10	6	8
30.	-----	-----	7	8

During these experiments Paris green has, except in one instance, killed the beetles in less time than zinc arsenite. Its killing time has been consistently shorter throughout than lead arsenate in quantities that it is practicable to apply. The results from Bordeaux mixture do not justify its use in this connection. Of the beetles poisoned during these experiments very few remained in sight. Most of them were to be found among the bases of the stems or under clods about the base of the plant.

REPELLENTS.

To determine what substances possess the greatest repellent properties, part of a cluster of beet plants was sprayed with Paris green, part with Bordeaux mixture, part with fish-oil soap, part with nicotine sulphate, and the remainder with water. A large screen cage was then set over the beets and about 70 beetles introduced. They scattered over the plants indiscriminately, but none fed on the ones treated with Paris green and Bordeaux. A little foliage was eaten from the plants treated with nicotine sulphate and soap. The beets sprayed with water were defoliated.

CONTACT INSECTICIDES.

Lime-sulphur in strengths up to 30 per cent did not produce satisfactory results. The weaker solutions had no effect on the beetles and the stronger ones stunted the beets.

Whale-oil soap, 1 pound to 2 gallons of water, killed beetles that could be thoroughly wet, but injured both sugar beets and potatoes on which the applications were made. No other contact insecticides were tested.

CONTROL MEASURES IN INFESTED FIELDS.

On June 23, 1913, blister beetles attacked a half-acre field of sugar beets at the Garden City branch of the Kansas Experiment Station. Most of them were the small-spotted blister beetle (*Epicauta maculata*), but the outbreak included a few of a large gray blister beetle or spotless blister beetle (*Macrobasis immaculata*). The little four-leaved plants had been stripped to the midribs over most of the field, and on the remainder the beetles were feeding. They were also crossing the road into a patch of Irish potatoes.

The beets where the beetles were feeding were sprayed with 1 pound of lead arsenate in 9 gallons of water. Part of the potatoes were sprayed with 1 pound of zinc arsenite in 32 gallons of water, part with 1 pound of Paris green and some lime in 40 gallons of water, and the remainder left as a check. The beets were so small and so badly eaten before being sprayed that they never recovered.

The sprayed potatoes were only slightly injured by the beetles, but the unsprayed ones were defoliated (fig. 22).

On July 5 a small patch of potatoes, grown by Dr. C. O. Townsend of the Bureau of Plant Industry for experimental purposes, was attacked by blister beetles of several species. The potatoes were being sprayed with Bordeaux mixture, so Paris green was added thereto for part of the patch and zinc arsenite for another portion. The potatoes designed to be left as a check on the Bordeaux treatment were sprayed with Paris green alone. These potatoes suffered



FIG. 22.—Field of potatoes attacked by blister beetles; strip through middle left unsprayed. Sprayed on left and on extreme right. (Photo by Lill, Bureau of Plant Industry.)

very little during the attack. Another invasion occurred three weeks later, at which time the potatoes were all sprayed with Paris green, 1 pound to 25 gallons of Bordeaux where the latter was used, and the same strength alone on the remainder. No damage resulted from the second attack.

Three acres of sugar beets belonging to Mr. D. A. Sheaks, of Garden City, Kans., were attacked by blister beetles that gathered in one edge of the field, most of them being large beetles (*Macrobasis immaculata*). On July 26 about half of the field, including the infested portion, was sprayed with $1\frac{1}{2}$ pounds of Paris green and some stone lime in 50 gallons of water. The beetles ceased their injury on the sprayed portion of the field, those that escaped collecting on beets on the unsprayed area. Not more than 25 per cent of them were killed.

On July 28 blister beetles from a freshly cut field of alfalfa gathered in a one-acre field of beets. About one-third of the patch

was sprayed, 1 pound of Paris green and some lime in 25 gallons of water being used. Another half-barrel of the solution was then prepared, the nozzles were changed for others having smaller openings, and the spraying was completed, only about a third of the second half-barrel of solution being used. The next morning dead beetles were numerous among the bases of the leaves and under clods. Those that remained alive were mostly stupid and helpless. The beetles were *Epicauta cinerea* and *Macrobasis unicolor*, which are of only medium size.

On July 25, 1914, a test was started at the Garden City branch of the Kansas Experiment Station on two tenth-acre plats that had been attacked by blister beetles to determine the comparative value of spraying and dusting. Paris green was used as a spray, 1 pound to 25 gallons of water; as a dust, 1 pound to 5 pounds of powdered lime; and lead arsenate was used as a dust without dilution. Part of each plat was treated with each formula. There was no perceptible difference in results. Of the small beetles (*Epicauta maculata*) a large percentage were killed, but of the large ones (*Macrobasis segmentata* Say, and *Macrobasis immaculata*) more escaped than were killed.

DRIVING.

When disturbed while feeding blister beetles drop or climb down rapidly to the ground and run away, sometimes traveling several yards before stopping to feed. Fields that are attacked by them may often be saved by taking advantage of this habit and driving them off. Several persons form a line and advance through the field, knocking the beetles from the plants with brooms, sticks, or pieces of brush. The advance should be slow, allowing time for killing any beetles that fall behind. At Garden City five persons in half a day drove the beetles out of 25 acres of beets. The method is to be recommended where most of the beetles are of the large varieties, where the plants are small and unable to survive defoliation if it occurs, or where for any reason immediate results must be secured. It is not practicable where abundant foliage affords concealment for the beetles.

SUMMARY OF CONTROL MEASURES.

Attacks by the smaller beetles are easily controlled by spraying with 1 pound of Paris green with lime in from 25 to 40 gallons of water. Many of the larger species are killed by the stronger solution. Dusting with 1 pound of Paris green to 5 pounds of powdered lime or with pure lead arsenate is effective against the small beetles, but can not be recommended against the larger ones. Driving the beetles out of the field is recommended wherever the work of the beetles must be checked at once.

The application of control measures for blister beetles must take into account the relation of these insects to grasshoppers. As long as the latter are present their eggs provide food for the young of the beetles. The destruction of the grasshopper eggs leaves the blister-beetle larvæ without food, thus being doubly beneficial. Incorporating into the farm practice of a community the simple measures that are known to hold grasshoppers in check will eliminate the danger from blister beetles.

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BUYING FARMS WITH LAND-BANK LOANS.

A STUDY BASED ON THE EXPERIENCE OF 2,700 FARMERS WHO
HAVE BORROWED MONEY THROUGH FEDERAL FARM LOAN
BANKS.

By L. C. GRAY, *agricultural economist*, and HOWARD A. TURNER, *junior agricultural economist*.

(Section of Land Economics, L. C. Gray, *agricultural economist, in charge.*)

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PURPOSE AND METHOD OF STUDY.

The increase of farm tenancy in the United States and the steady migration of farmers and farm laborers to the cities have called attention forcibly to the need for effective means of assisting men in acquiring farms.

Since the outbreak of the recent war there has been much agitation for Government initiative in the opening up of undeveloped land, with an accompanying tendency to ignore the importance of facilitating the acquisition of farm land in regions already developed. To become a farmer in undeveloped regions involves much risk and hardship, including adjustment to new methods of agricultural practice, and frequently separation from relatives and friends. In developed regions the continual retirement of farm owners from active

work is likely to result in a rapid increase of tenancy unless it is readily possible for landless farmers to buy the lands previously operated by these retiring owners. It is true this transition to ownership is partly effected through inheritance, marriage, or gift, but this is the case only to a limited extent. To a great extent farm ownership among the new generation of farmers must result from purchase.

When the Federal farm loan system was under consideration it was widely believed that it would be an important instrument in reducing the percentage of tenant farmers. Those best acquainted with its provisions realized, however, that, while the act would prove serviceable in this regard, the credit permissible under its somewhat

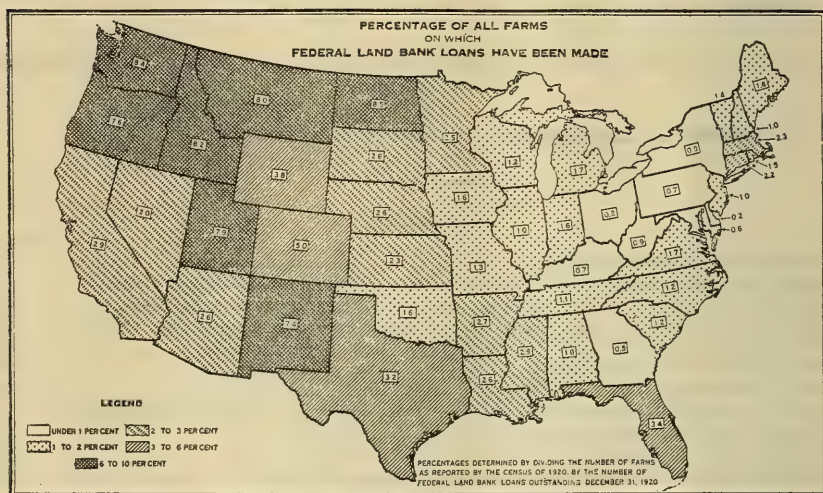


FIG. 1.

conservative provisions was made too small to effect a marked reduction in tenancy.

Since the Federal farm loan system has been in operation for about four years, it is important to determine the extent to which it facilitates the acquisition of farms by landless farmers, especially by those having little capital.

From this point of view the present study was undertaken to determine (1) what proportion of those borrowing under the Federal farm loan system for the purpose of buying land belong to the class just mentioned—that is, landless farmers with limited capital; (2) what methods such persons have employed to supplement the funds obtained from the Federal land banks; and (3) what have been the costs of Federal farm loans to the borrowers.

The point should be emphasized that the present study is not undertaken with the view of criticizing the farm loan system, its officials,

or its methods. Since the organization of the system notable progress has been made in extending its influence. Up to December 31, 1920, loans amounting to \$369,242,464 had been granted by the 12 Federal land banks. Moreover, the ratio of the loans to the total number of farms appears to be high in those sections of the country where farm credit had been costly to the farmer. (See fig. 1.) In fact, it is probable that in parts of these regions the system has been an important influence in improving the terms of credit obtained by the farmers through private agencies.¹ In short, the fundamental purpose of the present study is merely to determine the extent to which the system provides for the needs of the landless farmer seeking to buy farm land.

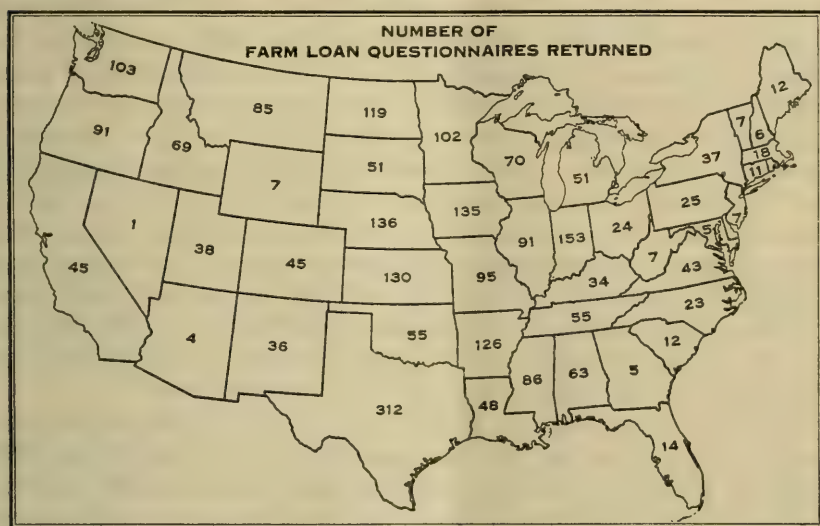


FIG. 2.—Distribution of some 2,700 replies received to questionnaire.

Some information on this point has been published by the Federal Farm Loan Board. These figures are presented in the following discussion. To supplement this information, 12,000 questionnaires were sent to persons who have borrowed under the Federal farm loan system, ostensibly for the purpose of buying farm land.² Approximately 2,700 replies were received, distributed as shown in the accompanying map (fig. 2). These replies constitute the principal basis of the discussion which follows.

The data are presented and interpreted on pages 5 to 20, following. The general conclusion derived from the data will be found on

¹ Second Annual Report, 65th Congress, 3d Session, House Document 1624, p. 5.

² The authors are indebted to the Federal Farm Loan Board for furnishing the addresses of these borrowers.

pages 20 to 23. Following these conclusions an attempt has been made to outline some constructive suggestions as to how the Federal farm loan system might be modified to render it more capable of facilitating farm ownership.

EXTENT TO WHICH FEDERAL FARM LOANS HAVE BEEN USED IN PURCHASING FARM LAND.

An analysis of 78 per cent of the total number of loans from the time of the organization of the Federal land banks to November 30, 1919, indicates that only 13 per cent of the amount thus loaned was for the purpose of purchasing farm land.¹ It is probable, however, that even this small percentage represents an increase in the proportion of loans for this purpose. An analysis of about one-third of the loans made prior to November 30, 1918, indicates that only 8 per cent of the proceeds were used for buying farm land.² If the proportion of loans analyzed is representative, within a year the proportion of the total number of outstanding loans made for buying farm land increased from 8 to 13 per cent. As this year was a period of rapid growth in the volume of business, the total amount of loans being nearly doubled, this increase appears to indicate a tendency toward the more extensive employment of the system as an aid in buying farm land. The tendency appears to be confirmed by special records kept by the regional banks at the request of the Farm Loan Board during the month of October, 1919, which indicate that 16 per cent of the loans made during that month were for this purpose.³

The smaller call on the Federal land banks during the earlier period to aid in buying land may probably be attributed to the fact that the Federal farm loan system became most favorably known, at first, among those farm owners who had been paying high interest and renewal charges on existing mortgages. Undoubtedly they were in large part men who organized most of the farm loan associations. Out of \$251,426,600 of the loans made from date of organization to November, 1919, 59 per cent was borrowed to liquidate existing mortgages, and an additional 9 per cent for the payment of other debts of borrowers.

¹ Third Annual Report of the Federal Farm Loan Board, 66th Congress, 2d session, House Document 553, p. 11.

² Second Annual Report, 65th Congress, 3d session, House Document 1624, p. 8.

³ A table which appears on page 58 of the hearings before the Senate Committee on Banking and Currency of the 66th Congress, 2d session, January 10, 12, and 13, 1920, indicates that a larger proportion of the loans made by the joint-stock land banks are made for the purpose of buying land than is the case with the Federal land bank loans. This table shows that of a total of \$53,008,983 in loans made by 24 joint-stock land banks from organization to January 1, 1920, 26.5 per cent had been made to farmers buying their first land, 21.4 per cent to persons buying additional land, 8.3 per cent for the purpose of making improvements, and 43.8 per cent to pay existing indebtedness. In short, not far from half had been used to buy land.

EXTENT TO WHICH LANDLESS FARMERS HAVE BEEN AIDED BY THE FEDERAL LAND BANKS.

It will be clear also that by no means all of the loans made for buying farm land represent the borrowings of landless persons. A considerable number of such borrowings may be made by persons who already own farm land. Such persons may be operating the farm owned, or they may be renting it to others while they are themselves operating land as tenants.

TABLE I.—Federal land bank borrowers buying land who answered the questionnaire, classified from the standpoint of ownership of other land and of tenure status as farm operators.

Class.	Total in each group.		Owning other farm land.		Not owning other farm land.	
	Number.	Per cent of group.	Number.	Per cent of group.	Number.	Per cent of group.
Tenants.....	752	36.6	285	37.9	467	62.1
Not tenants.....	1,290	62.8	1,077	83.5	213	16.5
Not indicated whether tenants or not tenants.....	12	.6	6	50.0	6	50.0
Total.....	2,054		1,368	66.6	686	33.4

Table I presents a classification of 2,054 borrowers purchasing land for whom the facts regarding tenure and ownership status were ascertainable from the returned schedules. It will be noted that almost exactly two-thirds of these borrowers owned land other than that which they were buying by the aid of the Federal farm-loan system, and only one-third belonged to the landless class. When one bears in mind that probably not more than 15 per cent of the loans made by the Federal land banks have been for the purpose of buying farm land; that only one-third of these borrowers were landless, assuming the above answers to be representative; and, finally, that the total loans of the Federal land banks probably represent only about 8 per cent of the entire farm-mortgage indebtedness of the United States, it will be clear that the direct aid afforded by the system to the landless farmer in the acquisition of land has been relatively small. It should be noted, however, that it is a much larger proportion of the total new business. Moreover, not all landless farmers are persons who require unusually favorable credit facilities to aid them in buying farm land, for some landless farmers have wealth which may be used in buying land, and some landless persons who desire to buy farms are not farmers at all.

It is probable that the relative use made by landless farmers will increase as the possibilities of the Federal farm-loan system for financing the purchase of farms becomes better known among this class. The small proportion of the loans made to total mortgage in-

debtedness is largely owing to the newness of the system, and the rapid progress made in the past few years would seem to guarantee that its relative importance as a source of farm loans will be greatly increased in the future. It is also probable that the influence of the system has resulted in more favorable terms for loans made, and has thereby indirectly facilitated the acquisition of farms by landless farmers.

One might well expect that the proportion of loans made for the purpose of buying farm land would be smaller than the proportion made for the refunding of existing indebtedness for farm improvements and for other productive purposes. Because of the short period for which the average farm mortgage runs, as made by private agencies, the proportion of renewals to the total number of loans is large in any one year; and, except in "boom" periods, the rate of turnover in farm land is small.

Some light on the relative extent to which loans made by private agencies are used for various purposes is obtainable from previous studies made by the Department of Agriculture of rural credits. In 1913 it was shown that for the entire country loans were made for various purposes in the following proportions: To improve, 49 per cent; to purchase, 28 per cent; to refund, 23 per cent. Of all loans, 74 per cent were renewed.¹ Taken on this basis, the per cent of Federal land bank loans made for the purchase of land does not appear to have reached the proportion of private loans made for the same purpose.

It appears that the Federal farm loan system has demonstrated its possibility as an aid to the landless farmer in acquiring land. Further analysis of its use by borrowers indicates that it provides conditions considerably more convenient for the buyer who must finance a large part of the purchase price on credit than are afforded by the great majority of private agencies engaged in farm mortgage business. This, however, does not imply that the system could not be further modified so that it could be more readily employed in financing the purchase of farms by landless men of small capital.

USE OF THE FEDERAL FARM LOAN SYSTEM BY TENANTS AS AN AID IN BUYING FARM LAND.

As shown in Table I, 36.6 per cent of the Federal land bank borrowers reporting the purchase of land were tenants. No attempt was made in the inquiry to ascertain the status of the remaining borrowers, but various replies indicate considerable numbers of nonfarmers, both owning and not owning land, as well as of farmers operating as owners of all or part of their farms. Of the total number of ten-

¹ Testimony of Mr. C. W. Thompson before the subcommittee on Banking and Currency, House of Representatives, 63d Congress, 2d session, Dec. 3, 1913.

ants 37.9 per cent own other farm land, and 62.1 per cent are landless, while in the case of nontenants the per cent owning other farm land is much higher, amounting to 83.5 per cent. Of the total number of borrowers giving the facts regarding their previous tenure and the amount of land which they owned, 23 per cent consisted of landless tenants.

USE OF LAND ALREADY OWNED TO FACILITATE ACQUISITION OF NEW LAND.

While it was not always possible from the information obtained to determine the extent to which land already owned was used in buying other land, it seems clear that, in large part, the land already owned was employed in one way or another for this purpose. Out of 700 cases of borrowings made by farmers already owning land, 500, or over 70 per cent, seem to have borrowed on the security of land already owned as well as the land being purchased, for in this proportion of cases the amount of the mortgage was 50 per cent or more of the value of the farm purchased. In addition to the cases in which the inference is fairly certain, it is probable that of those who borrowed less than 50 per cent of the value of the new farm in order to make the purchase a considerable number had used the land already owned, either by selling it or by mortgaging it.

RATIO OF THE FEDERAL FARM LOAN TO THE VALUE OF THE FARM PURCHASED.

Table II gives, in the case of 1,168 loans, the average percentage of the value of the land bought which the first mortgage represented. It was necessary to omit from the table some of those owning other land, because of the possibility that the mortgage indebtedness might rest not only on the farm newly purchased but also on the additional land owned. That this was frequently true is indicated by the considerable number of cases in which the mortgage was more than 50 per cent of the value of the new land purchased.

TABLE II.—*Relative size of Federal farm loan obtained for different tenure groups.*

Tenure group.	Number of farms.	Average per cent Federal farm loan is of the cost of the farm purchased.	Average cost of farm purchased.	Average size of the Federal land bank mortgage.
Non-owning buyers.....	558	44.2	\$8,072	\$3,566
Owner-buyers, including tenant owners.....	610	41.5	9,652	4,007
Total.....	1,168			
Non-owning tenants.....	406	44.1	8,224	3,632
Owning tenants.....	133	42.4	9,620	4,077

It seems clear that, in general, persons borrowing to buy land have borrowed a larger proportion of the value of the land mortgaged than the average for all borrowers, which was found to be 37 per cent for \$251,426,600 out of the total \$282,007,781 outstanding Federal land bank loans November 30, 1919.¹ For owner-buyers the loan is 41.5 per cent of the value, while non-owning buyers appear to have found it necessary to borrow nearer the limit allowed by the Federal farm loan system, their loans averaging 44.2 per cent.

The figure 44.2 per cent is very close to the limit allowed by law for, although the loan may be 50 per cent of the value of the land, only 20 per cent is allowed on the value of permanent insurable improvements, so that the average percentage must be considerably less than 50 per cent of the value of the farm. In fact, on the basis of the ratio of the value of land to the value of buildings for the entire United States, as shown by the 1910 census, the average maximum that could be loaned under the law would be 44.5 per cent of the value of land and buildings combined. Thus, it is obvious that those borrowing for the purpose of purchasing land have approximated the maximum that may be borrowed under the law.

COST OF OBTAINING A FEDERAL FARM LOAN.

Objection is sometimes raised to the use of Federal farm loans on the ground of their initial cost. If it is expensive to obtain these loans the purchaser of land may not be willing or able to stand the added expense at the start over what it might cost him to obtain a temporary loan from some other source. Lack of comparable information makes it difficult to compare the cost of obtaining loans from the Federal land banks with the cost of obtaining farm loans from other sources. Answers to questions designed to elicit information on the cost of Federal farm loans were received from 1,765 borrowers, and these answers make it possible to present information on the average cost of these loans. This average cost amounted to \$50.84, or 1.43 per cent of the mortgage given to the Federal land bank, which averaged \$3,541.

Borrowers of small amounts find the loans from the Federal land banks relatively more expensive than larger borrowers do, and this makes it more difficult for the buyers of inexpensive or smaller tracts of farm land to finance their purchases. There were 347 borrowers reporting the cost of borrowing who gave mortgages to the Federal land banks for \$1,000 or less, and the loans cost these borrowers an average of \$36.01, or 4.82 per cent of the mortgage given. On the other hand, while the cost of borrowing averaged

¹ Third Annual Report of the Federal Farm Loan Board, 66th Congress, 2d session, House Document 553, p. 12.

\$82.74 for the 187 borrowers who gave mortgages to the Federal land banks for amounts between \$7,501 and \$10,000, this cost represented only 0.9 per cent of the mortgage given.

The borrower planning to finance the purchase of a farm through the aid of a loan from a Federal land bank has not only to anticipate the costs connected with getting the desired loan, but he must allow for the amount withheld as his pro rata share of bank stock, or 5 per cent of the total amount of the mortgage given. In other words, the 1,765 borrowers realized an average of \$93.57 for every \$100 of mortgage given to the Federal land banks; borrowers giving mortgages for \$1,000 or less realized approximately \$90 on every \$100 of mortgage given; and borrowers giving mortgages for amounts running between \$7,501 and \$10,000 realized approximately \$94.00 on every \$100 of mortgage given.

Tables III and IV give in some detail information on the cost of loans from Federal land banks, based on answers by 1,765 borrowers. (See also fig. 3.)

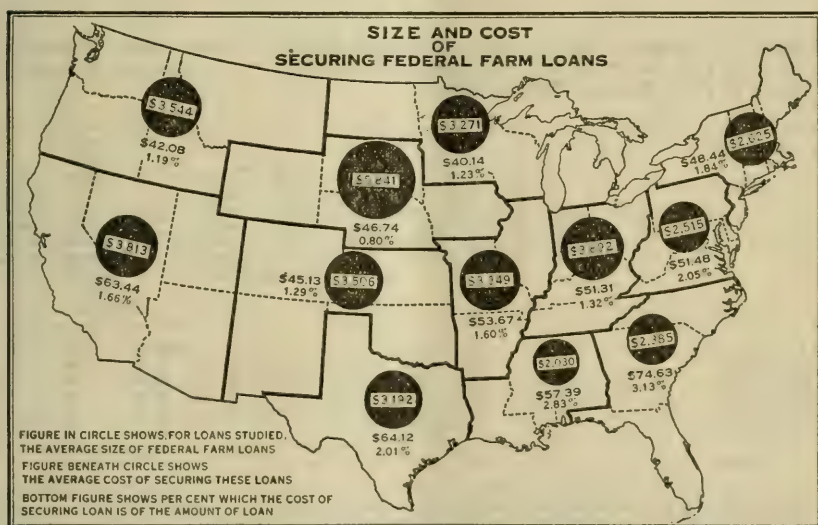


FIG. 3.—Size and cost of Federal farm loans, by land-bank districts.

TABLE III.—Costs incurred in obtaining Federal farm loans. (Analysis and averages of 1,765 reports.¹)

Size of average loan.....	\$3,541.00
Average cost of securing the Federal farm loan.....	50.84
Per cent which the average cost of securing the loan is to the loan.....	1.43

¹ Of the 1,765 borrowers reporting the cost of borrowing by items, 75.8 per cent reported expense for abstracting. It is probable that part of the expense reported under lawyer fees is also on account of abstract work done, especially in the First Land Bank District, comprising the New England States, New York, and New Jersey, where as many reported expense for lawyer fees as reported abstract expense and where the amount reported as lawyer fees exceeded that reported as abstract expense. Expenses itemized under the expression "application," "application fee," "association fee," "secretary fee," and "land bank fee" are probably not strictly correct in many instances, but if the total amount paid on all of these items is used that total amount may be considered as being fairly correct. In other words, it is thought probable that many borrowers did not correctly discriminate in entering amounts paid out to or retained by the land banks or association, although their total expense for such items is probably correct.

Elements of cost.	Per cent of all records reporting each item of cost.	Per cent of average cost represented.
Application.....	18.9	3.31
Application fee.....	33.2	6.58
Association and secretary fees.....	50.9	16.95
Land bank fee.....	34.7	9.71
Appraisal and costs connected with appraisal.....	34.9	7.35
Title determination by Federal land banks.....	18.4	3.75
All land bank and national farm loan association charges.....		47.65
Abstract of title.....	75.8	27.41
Extra abstracting.....	13.1	3.37
Title insurance.....	9.9	2.49
Surveying.....	6.1	1.58
Affidavits.....	12.2	.56
Legal papers and fees for filling them out.....	12.0	1.55
Lawyer fees.....	13.0	4.92
Notary fees.....	29.4	1.07
Recording fees and recording taxes.....	57.1	4.15
Internal-revenue tax stamps.....	39.1	1.92
Title charges, i. e., itemized charges other than those made by the land banks and national farm loan associations.....		48.82
Nonitemized charges.....		3.53
All charges.....		100.00

TABLE IV.—*Relation of the land bank and National Farm Loan Association charges and the costs in connection with the title to the amount secured on Federal farm loans of different sizes.*

Size of loan.	Number of mortgages averaged.	Size of average mortgage.	Total cost of mortgage.	Per cent cost of loan is of amount of loan.	Total land bank and association charges.	Title costs.	Per cent land bank and association charges are of mortgage.	Per cent title costs are of mortgage.
\$1 to \$1,000.....	347	\$747	\$36.01	4.82	\$10.90	\$22.38	1.46	3.00
1,001 to 2,500.....	530	1,815	41.28	2.27	16.37	23.63	.90	1.30
2,501 to 5,000.....	483	3,705	50.43	1.36	24.39	23.86	.66	.64
5,001 to 7,500.....	205	6,392	68.09	1.07	35.55	29.60	.56	.46
7,501 to 10,000.....	187	9,186	82.74	.90	52.01	27.32	.57	.30
10,001 and over ¹	13	16,231	120.23	.74	90.04	27.91	.45	.17
All cases.....	1,765	3,541	50.84	1.44	24.21	24.64	.68	.70

¹ While \$10,000 is by law the maximum which may be borrowed by one person from Federal land banks, larger loans are evidently secured on what some borrowers consider to be one farm. This might be the result if two or more persons owned distinct parts of what may be operated as a single farm, each owner obtaining a loan on his part of the farm from the Federal land bank.

The prospective purchaser of land who plans to buy with money, part of which he borrows from a Federal land bank, should give due consideration to the possibility of delay in the completion of negotiations for a loan. Cases have occurred in which prospective buyers have made deposits on land to secure a contract of sale, which contract they have forfeited because they were unable to complete the purchase, money which they depended upon Federal land banks to furnish being held up for one reason or another. Frequently, delay is due to failure to comply with the requirements of the Federal land

banks regarding the title to property; but the possibility of delay for other reasons, such as the impracticability of the appraiser for the land bank promptly viewing the land, should be foreseen, and the contract of sale should be made to cover a sufficient time.

METHODS EMPLOYED TO FINANCE THE PURCHASE PRICE ABOVE THE AMOUNT OBTAINED FROM THE FEDERAL FARM LOAN SYSTEM.

A question of special interest in the present study is, How did those who borrowed from the Federal land banks for the purpose of buying farm land finance the remainder of the purchase price above the amount obtained by first mortgage? Or, more particularly, To what extent were second mortgages employed for this purpose, and what were the terms of these second mortgages?

EXTENT OF USE OF SECOND MORTGAGES.

To answer these questions it is possible to use 1,008 replies in which a complete record of the conditions of purchase were given. Of this number, 477 did not involve second mortgages, while 531 did. Of the latter number, second mortgages were given to relatives who were also sellers of the land in 43 cases, and to other sellers in 372 cases. Thus in practically 78 per cent of the cases the second mortgage was given to the sellers of the land—that is, to persons who might presumably be interested in giving specially favorable terms. In only 22 per cent of the cases were the mortgages given to others than sellers of the land.

The terms of purchase for these 1,008 cases are summarized in Table V.

TABLE V.—*Use of the second mortgage by borrowers from the Federal land banks in order to complete the purchase.*

Class of case.	Number of records.	Averages.						
		Cost of farm.	Cash or trade. ¹	Second mortgage.	Interest rate on second mortgage.	Per cent in—		
						Federal loan.	Second mortgage.	Cash or trade. ¹
No second mortgage given.....	477	\$8,294	\$4,912	.....	.....	41.0	.....	59.5
Second mortgage given.....	531	9,874	2,414	\$3,363	6.7	43.3	34.1	24.4
Second mortgage held by:								
A relative who is the seller.....	43	12,807	2,209	5,087	5.8	43.9	39.7	17.3
Other sellers.....	372	9,162	1,983	3,424	6.6	43.3	37.4	21.6
Parties other than sellers.....	116	11,069	3,873	2,527	7.2	43.1	22.8	35.0
All cases.....	1,008	9,126	.....	.....	.....	42.7	.....	.....

¹ This item includes some of the expenses incident to borrowing.

As one would expect, those finding it necessary to borrow on second-mortgage security obtained a larger average per cent of the purchase price on first mortgage than did those who did not employ second mortgages.

The 477 buyers giving no second mortgage gave first mortgages to the Federal land banks that averaged 41 per cent of the cost of the farms purchased. The remainder of the purchase price was paid in cash or by trading other property. The 531 buyers giving a second mortgage additional to the first held by the Federal land banks, which averaged 43.3 per cent of the cost of farms purchased, obtained 34.1 per cent of the cost of the farm on the second mortgage. The amount put in by this group in cash or trade averaged 24.4 per cent of the cost of the farm.

INFLUENCE OF PERSONAL RELATIONSHIPS ON THE TERMS OF SECOND MORTGAGES.

The better terms on which farms are bought by men who are able to get relatives to accept second mortgages, whether buying from such relatives or from others, are reflected by the averages for the group of 43 buyers who bought, giving second mortgages to their relatives. The second mortgage held by relatives of the buyer averaged 39.7 per cent of the cost of the farm and bore interest at the average rate of only 5.8 per cent per annum, little more than the total annual cost of the first mortgage. The amount put in by this group in cash or trade amounted to only 17.3 per cent of the cost of the average farm. These men bought farms averaging \$12,807 in value, this amount averaging higher than the farms in any other group. That the price paid was reasonable in most cases is indicated by the fact that 43.9 per cent of the purchase price was accepted as mortgage by the Federal land banks.

When sellers of land, even when not related to the buyers, accept a second mortgage in part payment, they are frequently willing to give favorable terms of credit because they are anxious to effect a sale. This tendency is reflected in the terms of second mortgages given to former owners (Tables V and VI). It appears that in this group the second mortgages averaged 37.4 per cent of the purchase prices of the farms. This is slightly less than the percentage for mortgages given to relatives who were sellers, but much higher than the proportion of the purchase price (22.8 per cent) represented by mortgages given to persons who were not sellers. The tendency toward favorable terms in mortgages held by sellers of farm land who are not related to the buyers is shown by the average interest rate of 6.6 per cent, as compared with an average of 7.2 per cent on mortgages held by persons other than sellers.

It is probable that the terms on mortgages given to the class of persons other than sellers represent fairly closely the typical conditions for ordinary commercial loans on second mortgages. However, some of these loans may have been given to relatives or other persons who had some special motives for granting specially favorable terms.

The need of popularizing the second mortgage when given in connection with the purchase of a farm through the aid of a first-mortgage loan obtained from the Federal land banks is strongly suggested by the fact that, of the entire number of farms purchased on which second-mortgage loans were obtained, only 116, or 22 per cent of the entire 531, were taken by men who were reported neither as relatives of the purchaser nor as the former owners of the land. If second mortgages given in connection with Federal farm loans were looked upon with more favor by men having money to lend, there would doubtless be a wider use of the Federal land bank mortgage as a means of acquiring land by persons having a small amount of money, but not enough to operate a farm and pay for the full amount of its cost not covered by a loan which they could get from a Federal land bank.

PROPORTION OF PURCHASE PRICE OBTAINED ON SECOND MORTGAGE.

In Table VI is shown the percentage of the purchase price represented by second mortgages in the case of 527 farms purchased through the aid of second mortgages, for which complete data are available. Of these, 167, or 32 per cent of the second mortgages, were for one-fourth or less of the purchase price, and 18 per cent for more than half of the purchase price. Men who purchased from sellers who were not their relatives, but who were willing to accept the second mortgage in lieu of part of the cost of the farm, placed more than half of the cost of the farm on second mortgage in 22 per cent of the cases. Of the men who were able to get relatives to accept the second mortgage, 10 out of a total of 32, or 31 per cent, were accommodated with second mortgages which represented more than half of the purchase price of the farm. On the other hand, only 4 of the 107 second mortgages which were held neither by the former owner of the land nor by a relative of the buyer of the farm were for more than half the cost of the farm.

TABLE VI.—*Purchasers classified according to promotion of price raised on second mortgage and relationship to former owners.*

[Giving of mortgages coincident to the purchase of farms, and first mortgages held by Federal land banks.]

Per cent second mortgage is to total cost of the farm.	Number of records.	Per cent of all records.	Holders of second mortgage—		
			Former owners.		Not former owners. (107 records).
			Related to the purchaser. (32 records).	Not related to the purchaser (388 records).	
			<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
1 to 25.....	167	32	10	26	60
26 to 40.....	157	30	34	30	27
41 to 50.....	105	20	25	22	9
Over 50.....	98	18	31	22	4

PERIOD OF REPAYMENT OF SECOND MORTGAGES.

By placing as large an amount of the cost of the farm as possible on first and second mortgages, the purchaser who is short on cash husbands his resources so that he may have enough on which to operate his farm. But the conditions of repayment on his mortgages should be such that he will not be embarrassed in meeting the payments.

On the first mortgage given to the Federal land bank he must pay $6\frac{1}{2}$ per cent each year (if the mortgage was given on or after December 7, 1917), this amount sufficing to pay the interest due each year and to reduce the principal so that in $34\frac{1}{2}$ years both principal and interest will have been fully paid. The payments on the Federal land bank loan are made annually or semiannually, and the comparatively small payments to be made at any one time should not embarrass the borrower.

Table VII shows the time by which the second mortgages were found to be fully payable as shown by 576 second mortgages made in connection with the purchase of farms on which loans on first mortgages were obtained from Federal land banks. Two out of every 10 of these second mortgages were payable in full by the end of the second year and seven out of every 10 by the end of the fifth year. A larger number of second mortgages were payable in full by the end of the fifth year than by the end of any other period, 29 per cent having the fifth year specified as the date of final payment. Only one out of every 20 was not fully payable by the end of the tenth year. A larger proportion of the buyers who borrowed on second mortgages from relatives were allowed longer than two years than in the case of those who borrowed from others than relatives, and a larger pro-

portion who borrowed on second mortgages held by the former owner were allowed longer than two years than was the case with those who borrowed from men who were not the men from whom they purchased.

SIZE OF SECOND MORTGAGES RELATIVE TO COST OF FARM PURCHASED AND WHEN SECOND MORTGAGES COME DUE																
PER CENT SECOND MORTGAGE IS OF COST OF LAND	DOTS REPRESENT SECOND MORTGAGES MATURING EACH YEAR														NUMBER OF RECORDS	PER CENT OF ALL RECORDS
	YEAR BY WHICH SECOND MORTGAGES MUST BE FULLY PAID															
	1	2	3	4	5	6	7	8	9	10	11-15	16-20	21-30	31+		
61 +		•	•••	•	••• •	•	•••	••	•	••• ••	•	••	•		39	74
51-60	•••	•	•• •	••	•••• ••••	•••	•••	••		•••• ••••	••	••	•		59	112
46-50	••• •	••• •	•••• ••••	••• ••••	•••• ••••	••	••	•••	•	••• •	•	••			72	391
41-45	•••	••	••	•	••• ••	••	••	•••	•	•••	••			•	33	93
36-40	••• •	••	••• •	•••	••••• •••••	••	••	••		••• •••	••	•			59	113
31-35	••	•••	••• ••	•••	•••• ••••	••	•			•		•••			52	98
26-30	••• •	••• •	•••	••	•••• ••••	•		•••		••		•			46	67
21-25	••• ••	••	••• •	••	•••• ••••	•••	•	••		••• ••	•			•	51	84
16-20	••••	••••	•••• •	•••	••••	••				••					57	108
0-15	•••• ••••	•••• ••••	•••• •		•••• ••••				•	•	•				59	112
PER CENT OF ALL RECORDS	11.2	9.3	15.5	6.4	29.0	4.2	4.6	4.3	0.8	9.7	2.1	2.1	0.4	0.4		100
NUMBER OF RECORDS	59	49	82	34	153	22	24	23	4	51	11	11	2	2	527	

FIG. 4.—Analysis of terms of 527 second mortgages given in connection with purchase of farms for which the first mortgages were held by Federal land banks.

TABLE VII.—Time by which second mortgages are fully payable.

[First mortgage held by Federal land banks, and giving of mortgages coincident to the purchase of the land.]

Holder of second mortgage.	Number of records.	Per cent fully payable—				
		By end of second year.	After second but by end of fifth year.	After fifth but by end of tenth year.	After tenth year.	Special (usually no fixed maturity).
Relative who is former owner.....	36	5.8	41.7	36.1	5.5	11.1
Other former owners.....	305	17.0	48.4	27.6	6.6	.3
Other than former owners.....	145	33.1	53.8	8.3	2.1	2.8
All cases.....	576	20.3	49.3	23.3	5.4	1.7

It also appears that, in general, the period of repayment tends to be longer in the case of second mortgages which represent a comparatively large proportion of the purchase price. For 527 records of second mortgages made in connection with the purchase of farms and with the giving of a first mortgage to the Federal land banks, it was possible to determine the relationship between the period of repayment and the size of the second mortgage. Figure 4 shows in detail how many of all these mortgages were fully payable by the end of various terms, the records being grouped according to the relative size of the second mortgage.

Approximately three-fifths of those second mortgages which amounted to over half of the cost of the purchased farm were not fully payable until after the fifth year, and approximately one-fourth of those amounting to between two-fifths and half of the cost of the purchased farm were not fully payable until after the fifth year. On the other hand, approximately three-fourths of the second mortgages amounting to one-fifth or less of the purchase price were fully payable by the end of the fourth year, and over nine-tenths of them were fully payable by the end of the fifth year.

PROVISIONS FOR PERIODIC REPAYMENT OF SECOND MORTGAGES.

As in the case of Federal farm loans, provision for periodic repayment of the second mortgage loan is likely to be an important aid to the landless man possessing little capital. Table VIII shows the percentages of second mortgages repayable in various ways. Half of the second mortgages are payable at the end of the mortgage period without any provision for periodic payments to reduce the amount of the principal aside from instances where it was understood that the borrower had the privilege of paying off the second mortgage as he chose, usually at the interest paying date and in multiples of 50 or 100 dollars. Mortgages coming due as a lump sum at the end of the mortgage period occur with especial frequency in the group of 144 buyers who did not borrow on second mortgages from the man from whom they purchased the land; seven of every ten of these men have mortgages repayable in that manner. About two out of five borrowers were under obligation to make annual payments on their second mortgages. Borrowers who were indebted on second mortgage security to relatives were particularly favored as to the final payment of their second mortgages, a third of these borrowers being permitted to make full payment practically at their own option. Few cases of second mortgages repayable in monthly or semiannual payments were found.

TABLE VIII.—*Manner of repaying amount loaned on second mortgage.*

[First mortgage held by Federal land banks and giving of mortgages coincident to the purchase of the land.]

Holder of second mortgage.	All cases.	Per cent of second mortgages repayable—					
		Monthly.	Semi-annually.	Annually.	End of mortgage period.	Any time optional.	Other ways.
Relative who is former owner....	35	-----	2.9	17.1	40.0	34.3	5.7
Other former owners.....	398	1.0	0.3	46.7	44.5	1.5	6.0
Other than former owners.....	144	-----	0.8	20.1	70.1	7.6	1.4
All cases:							
Per cent.....	-----	0.7	0.5	38.3	50.6	5.0	4.9
Number.....	577	4	3	221	292	29	28

In Table IX second mortgages involving the privilege of periodic repayment are grouped according to the size of annual payments. There were 240 second mortgages repayable in periodic payments on which it was possible to determine the relation of the size of the periodic payments to the cost of the farm. Ignoring interest, it is found that about one-third of these 240 borrowers are under obligation to pay to the holder of the second mortgage, each year till the second mortgage is fully paid, an amount up to 6 per cent of the original cost of the farm by way of reducing the amount of the second mortgage. Payments larger than this, on second mortgages of any considerable size, would be rather hard to meet out of the income of the farm in addition to the payment of interest on the second mortgage, and interest and amortization on the Federal land-bank loan. Yet the greater number of the rest of these second mortgages are so arranged that there is annually due on the repayment of the second mortgage an amount exceeding 6 per cent of the cost of the farm in addition to the interest due on the second mortgage.

TABLE IX.—*Periodic repayment of second mortgages; size of annual payments.*

[Per cent of total cost of farm, ignoring interest.]

Annual payment.	Number of records.	Per cent of all records.	Annual payment.	Number of records.	Per cent of all records.
Up to 4 per cent.....	33	13.8	Over 15 per cent.....	15	6.2
4 to 6.....	45	18.8	Special cases.....	37	15.4
6 to 8.....	37	15.4			
8 to 10.....	36	15.0	Total.....	240	100.0
10 to 15.....	37	15.4			

In at least one instance the Federal farm-loan plan of repaying the interest and amortizing the principal has been copied by the seller of his farm in drawing up the terms of repayment on the second mortgage, which he accepted in part payment for his farm. In buy-

ing a Missouri farm at a cost of \$15,500 a man who up to that time had been a tenant put into the purchase \$2,500 of his own money. As to the balance of the purchase price he borrowed \$6,500 from the Federal land bank, and the man from whom he purchased took a second mortgage equal in amount to that taken by the Federal land bank and on the same terms, both as to interest and as to the size of the semiannual payment. These terms make it possible for this former tenant to own the farm clear of all encumbrances in $34\frac{1}{2}$ years from the time he purchased by making semiannual payments of \$422.25 until the end of that time, this amount so paid being sufficient to pay the interest and amortize the principal of both the first and the second mortgages.

Several purchasers reported that the man from whom they bought accepted a second mortgage, payable in full by the end of 20 years, interest on any unpaid balance being paid annually, and in addition an amount equal to a twentieth of the face of the loan, so as to pay off the second mortgage in full by the end of the twentieth year.

In another case the seller of a farm permitted the buyer to place a Federal land-bank loan on the farm, and accepted a second mortgage in part payment, due in 20 years, with provision for payments at the option of the purchaser up to the end of the twentieth year. In such a case the holder of the second mortgage has the assurance that his second mortgage is becoming more secure each year, because his mortgage is second to a mortgage that is being reduced in amount every six months by a payment on the principal.

The principle of deferring the first annual payment for more than one year after the negotiation of the loan is observed in a few of the second mortgages subject to periodic repayment. In two cases payments begin to come due on the second mortgages not until the fifth year, in seven cases in the third year, in five cases in the second year. However, most of the mortgages—228 in all—provide for the first payment by the end of the first year after the date of the second mortgage. Arrangements for deferred payment such as those just described are likely to prove of considerable advantage in the case of a purchaser who needs all his available cash during the first few years to place the farm on a paying basis.

RATES OF INTEREST ON SECOND MORTGAGES.

The interest rates on second mortgages were found to average 6.8 per cent. The rate for the various Federal land-bank districts is shown in figure 5. While the average rate is highest for the Texas land-bank district, which comprises the single State of Texas, it is considerably higher for several other individual States, for instance, Arizona, 10 per cent; New Mexico, 8 per cent; Arkansas, 8 per cent.

It is a striking fact that the average rate of interest on second mortgages is about the same as the average on first mortgages made by private lenders, as obtained by an earlier investigation made by the department. In fact, the average rate on first mortgages, 6.9 per cent, is slightly higher than the average for second mortgages. A comparison of average rates by Federal land-bank districts shows also a considerable degree of correspondence. (See figs. 5 and 6.¹) While the averages for the two classes of mortgages are only roughly comparable, the correspondence in the two rates is sufficiently close to suggest that probably rates on second mortgages do not tend to average much higher than those on first mortgages.

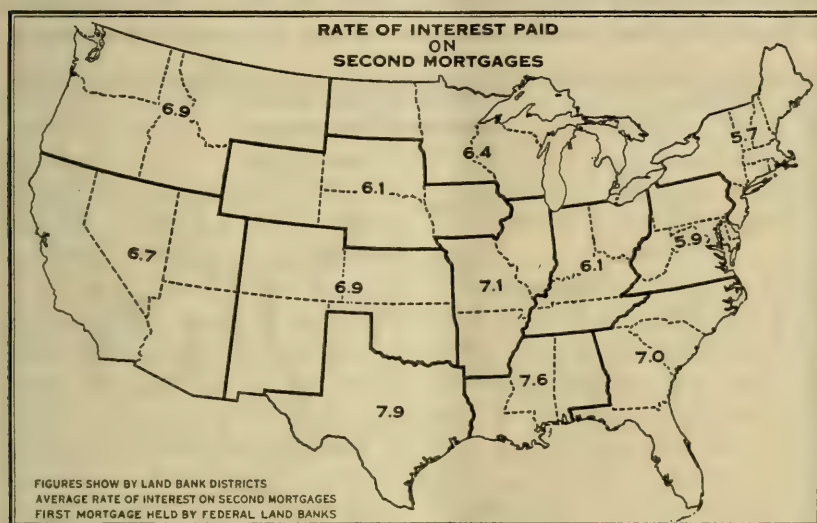


FIG. 5.—Average rate of interest paid on second mortgages, by Federal land-bank districts.

The tendency for average rates of interest on second mortgages to approximate closely the first-mortgage rates has been confirmed also by a recent survey of land sales in Iowa, where the average rates on second mortgages proved to be 5.7 as compared with 5.3 for first mortgages.²

At least two important conditions may be considered responsible for the tendency. In the first place, a large proportion of second mortgages are given to sellers of land who for one reason or another are willing to give better credit terms than would be allowed if the

¹ The data on first mortgages are based on reports for 47 States, the results of which are published in Department Bulletin 384. This bulletin gives no average for the entire United States. The average employed above, therefore, is an average by States. Moreover, the data were obtained in 1913. For these reasons the averages are only roughly comparable.

² Farm Loan Values in Iowa, by L. C. Gray and O. G. Lloyd, Bulletin 874, U. S. Dept. of Agriculture, p. 17.

loan were made on considerations of credit alone. In the second place, it is probable that legal restrictions on interest rates exert an important influence on normal interest rates for second mortgages, as well as in the case of first mortgages. In various ways additional charges probably are employed to supplement the normal interest rate. In general, this seems to be another indication of the fact that lending on second mortgages has not been widely developed on a commercial basis.

SUMMARY AND CONCLUSIONS.

The Federal farm-loan system has been employed to a considerable and an increasing extent to enable men to buy land. The proportion of loans for this purpose has probably not yet reached a maximum.

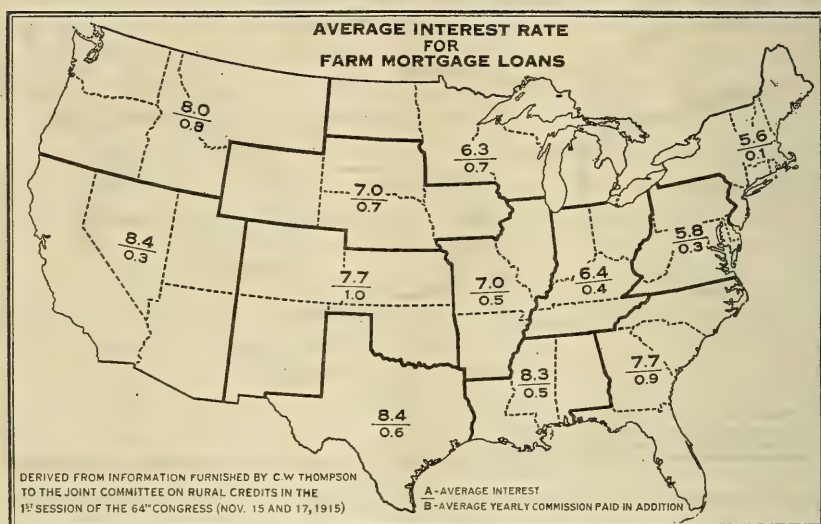


FIG. 6.—Average interest rates for farm mortgage loans, by Federal land-bank districts.

In addition to the loans made directly for this purpose, it is probable that loans made for refunding indebtedness and for other purposes improve the financial position of the farmer, to such an extent as to enable him to invest in additional land.

To a large extent the use of the system for acquiring farm land has been by those already owning farm land, about two-thirds of those who borrowed to buy land belonging to this class. Of the landless borrowers, about two-thirds were operating as tenants at the time of borrowing.

While it is apparent, therefore, that landless persons desiring aid in acquiring the ownership of farm land have not resorted extensively to the farm land banks, an examination of the methods employed by

this class to finance their purchases indicates that the Federal land banks provide more favorable conditions for the purchase of farms by those having but a small proportion of the purchase price than prevailed before the development of the Federal land bank system. This is true because the system makes it more practicable to lend on second mortgages than under the arrangements for farm-mortgage credit usually provided by private enterprise.

Prior to the development of the Federal farm loan system men who had money to lend were slow to put it out on second-mortgage security, and, broadly speaking, lending on second mortgage has never been well organized or extensively employed. As shown by this and other studies, a large majority of such loans are made by persons who are selling the land mortgaged and are willing to grant unusually favorable terms to effect a sale, or by relatives or others who are inclined on personal grounds to lend under easier conditions than are afforded by regular credit agencies. Probably a large proportion of the remainder of second-mortgage loans are handled by local individual money lenders or by country banks. Comparatively a small percentage of such loans are made by large organizations operating over a wide territory.

In part, this failure to develop second-mortgage credit on a commercial basis has been due to the prevailing system of first-mortgage credit as afforded by private agencies. With the short-time first-mortgage loan there is always considerable danger that foreclosure may take place, with resulting extinction of the equity of the holder of the second mortgage. Even were this danger not present, the necessity of repaying the first mortgage within so short a period greatly limits the borrower in safely assuming a margin of indebtedness above the first mortgage to be repaid in an equally short period. This limitation is increased in many sections by high rates of interest and commission and by conditions of renewal.

Most men who have money to lend do not care to put it out on second-mortgage security under ordinary conditions. Doubtless they are well justified in this conservatism when the second mortgage is preceded by a first mortgage that represents a large part of the sale value of the property, when that first mortgage bears so high a rate of interest or is repayable in such a way as to make it quite possible that the holder of the first mortgage may have to foreclose in order to make the borrower live up to its terms, or when the title to the farm is questionable. But the position of the holder of a second mortgage is far more secure when his mortgage is second only to a mortgage held by a bank of the Federal farm loan system. These banks are very careful in placing their loans, which are almost certain to be for less than half of the value of the farm, inasmuch as

they appraise conservatively, refuse to expand their loans because of boom conditions, lend only up to half of the appraised value of the land and one-fifth of the appraised value of the buildings, and are especially cautious in lending on such security as orchards and woodland. In fact, as shown above, the average ratio of the loan to the value of the land for all classes of buyers is only 37 per cent, while for landless persons borrowing to buy land it is only 44.2. Moreover, the Federal land banks refuse loans on the security of land for which good title can not be given. The lender on second mortgage may enjoy the benefit of this careful examination without extra expense either to himself or to the borrower. Year by year, as the borrower pays the amount required of him for interest and amortization, the position of a person holding a second lien becomes more secure, and there is no large final payment to be made on the first mortgage that is likely to result in foreclosure proceedings or to embarrass the borrower in meeting his obligations under the second mortgage. The interest rate on Federal land bank mortgages is low and the amount due as interest and payment on the principal is not large in proportion to the total value of the farm.

It is obvious that these conditions provide a far more favorable basis for second-mortgage loans than was provided by the usual types of first-mortgage loans on farm lands. It is not strange that numerous borrowers and lenders have taken advantage of this favorable opportunity to negotiate second-mortgage loans, and it is to be expected that regular private credit agencies may avail themselves to some extent of this opportunity.

It is doubtful, however, whether we can rely on private enterprise to develop extensive facilities for loans secured by second mortgages on farm property. Unless some special motive exists for making such a loan, such as desire to sell the land, it is not an attractive investment except at such a high rate of interest that it is likely to prove a millstone around the neck of the borrower. It is difficult to resell such mortgages in the general market unless indorsed by a large and well-known credit agency. Consequently they can not readily be made the basis of a profitable loan business in which the lender employs his capital in making loans to be disposed of to investors, making his profit out of a relatively small margin multiplied by the rate of turnover. In the case of first mortgages, trust companies and mortgage loan companies can make considerable profit by continually turning over their capital in this manner. It would appear, therefore, that if adequate credit arrangements for *bona fide* farmers who are attempting to buy farms with a small initial margin of capital are to be provided, it will be necessary to rely largely on the Government to make such provision.

Such arrangements are justified on the grounds of public policy. Home ownership is a basic element in the economic and social stability of the Nation. A large percentage of farm tenancy is unfavorable to an efficient and permanently productive agriculture and a wholesome and stable community life. Some tenancy is necessary, and probably even desirable. It is the part of good policy to accept this fact and to devote our energies to reducing the incidental evils; but it is also the part of good policy to prevent the proportion of tenants from becoming abnormal. So long as young farmers may as a rule hope to become owners of land after a series of years as tenants, tenancy is not fraught with the social evils which come with the establishment of a permanent tenant class; hence the importance of keeping the road open to the top.

One of the more important causes of the tendency in the direction of providing credit for farmers is the fact that the estimated average value of farm land and improvements in the United States appears to be between three and four times as great in 1920 as it was in 1900. This represents an increase of approximately \$20 per acre from 1900 to 1910 and \$31 per acre from 1910 to 1920.¹

In many parts of the country the value of a farm now represents a considerable fortune. Therefore it may be doubted whether in certain sections the average man can hope to accumulate such a fortune out of the profits of farming even in a lifetime. It is certainly exceedingly difficult in many sections of the country for a man starting with little or no property to accumulate in a reasonable length of time all that part of the purchase price of a farm in excess of the proportion usually lent on first-mortgage security. It would seem clear, therefore, that more liberal arrangements for farm-mortgage credit must be provided as an important phase in the development of a constructive policy with reference to farm land.

SUGGESTIONS FOR ADDITIONAL CREDIT ON SECOND-MORTGAGE SECURITY.

Although the purpose of the present study is to ascertain certain facts with regard to the employment of the Federal farm-loan system to finance the purchase of farms, it may not be out of place to consider, in the light of the facts brought out in this study, some of the broad lines that might be followed in providing additional credit facilities. In so doing the authors wish to disclaim any desire to formulate a cut-and-dried plan or to insist dogmatically on the suggestions here made. Moreover, only broad lines of policy are

¹ The above statement is based on census reports, using the preliminary figures for 1920.

suggested, and no attempt is made to consider details or to anticipate in discussion objections that might be raised.

Assuming that in many instances it will be necessary for the would-be purchaser to borrow a considerably larger percentage of the value of the property mortgaged than is now possible under the Federal farm-loan system, it is important to inquire whether the entire loan should be made on first-mortgage security or whether the borrower should be allowed to give a first mortgage for approximately the maximum now permitted and to offer a second mortgage for the remainder.

There are several strong reasons for the latter method. In the first place, the number of loans made to facilitate the purchase of land represents but a small proportion of the total loans on first mortgages. If special credit arrangements should be provided to farmers in becoming owners of their farms, it would not be necessary to extend these special advantages to persons borrowing for other purposes. In the second place, there is a well-established market for conservatively placed first mortgages, in which such mortgages can be resold by the lender, either directly or by issuing bonds secured by specific mortgages, and it would probably be difficult to educate investors to accept mortgages representing a much less conservative margin of credit. In the third place, the borrower is likely to desire, and probably should be required, to repay that part of his loan which exceeds the ordinary margin of credit allowed on first-mortgage security in a shorter period than is now allowed for first mortgages under the Federal farm-loan system. While this is not impossible when the entire loan is secured by a single lien, it is easier to require it, as distinguished from permitting it, when the excess represents a separate contract. In the fourth place, if the Federal farm-loan system were modified to permit a larger credit in some instances, even though such loans represented but a small proportion of the total volume of loans, it is probable that the knowledge of this fact would impair the general market for the bonds based on mortgages as security, and this would probably be the case even though all mortgages exceeding a conservative margin of credit were excluded as a basis for bond issues. Finally, if the system of farm credit should be modified to permit borrowing on a larger proportion of the value of security offered, as a means to home ownership, it would be desirable to provide special restrictions and regulations covering such cases which would not necessarily apply in the case of the larger volume of loans on first-mortgage security.

In providing a special system of second-mortgage credit in the interest of promoting farm home ownership it would probably be

desirable to restrict the benefits of such a system to those whom the act was designed to serve. Not only should it be restricted to the single purpose of buying farm land, but it should also be requisite that the borrower establish the fact that he seeks the aid of the system as a means of becoming an operating farm owner and for a reasonably long time. It might also be possible to devise a method of indirectly limiting the benefits of the system to men of small capital. The system should not facilitate the acquisition of additional farms or even of additional land except when the latter represents a *bona fide* attempt to enlarge or round out a holding previously inadequate for economical operation. Proper administrative safeguards should be provided to insure that the cost of the farm is reasonable enough to justify the presumption of the buyer's paying out on the investment and also that the buyer has sufficient experience and personal ability to justify his undertaking a farm enterprise. Provision should be made to prevent the use of the system for speculation. It seems probable that, thus restricted, the suggested provisions would serve the purpose of promoting farm home ownership on the part of those who would be prevented from attaining that status under present conditions of land values and mortgage credit, and without involving a heavy drain on the Nation's farm-credit machinery.

Such a system might be developed on thoroughly businesslike principles without committing the Nation to anything approaching a class subsidy. It would probably be possible to make such a system pay its way without subjecting the Government to unreasonable risks. Prevailing systems of first-mortgage loans, including the Federal farm-loan system, are based on the theory that each individual mortgage must be absolutely safe, so that in case of foreclosure there will be no reasonable doubt that the value of the farm will repay the debt. This policy is largely due to the practice of reselling individual mortgages or blocks of mortgages or of assigning them as security for bond issues. In fact, it is usually the intent to avoid even the possibility of foreclosure, for most agencies lending on farm mortgages do not care to incur serious risk of having to take over the ownership of the land.

The conservative character of the Federal farm-loan system is due to the fact that it is based on this principle; a fact that renders it useful as a general basis of long-time farm credit, but limits its usefulness as an agency to promote farm ownership among those seeking to establish themselves in the land with limited capital.

It would seem, however, that a system of second mortgages under Government auspices might be developed on the insurance prin-

ciple. Instead of seeking to avoid all risk, such a system would carefully estimate the risks incurred and spread this risk over a large number of loans widely distributed in different sections of the country, charging enough extra on the interest rate to earn the actuarial value of the risk assignable to the particular loan. Such charges could be graded for different degrees of risk. The larger the credit desired the higher the per cent of charge to be added to the basic interest rate. The charge might also be varied according to the section of the country, being made higher, for instance, in regions where frequent drouths occur.

It is obvious that such a basis for credit could not be safely adopted by any agency with only a small volume of loans nor by one whose loans were confined to a single section of the country. For the last-mentioned reason it could not well become a basis for a local system of credit, but might be feasible for an agency doing a large business on a nation-wide scale.

If such a system were developed to supplement the Federal farm-loan system it would be necessary to offer its privileges only to those cases in which the first mortgage is held under the Federal farm-loan system, for the element of risk on the second mortgage would be greatly reduced if both first and second mortgages were controlled by the same agency. Holders of second mortgages have always been faced by the danger of arbitrary foreclosure of the first mortgage, with the resulting destruction of the second-mortgage equity. Many first-mortgage loans are made with the expectation of renewal. If, however, the holder refuses to renew, he may foreclose and force a sale of the property. This may occur even though the farm business is to all intents and purposes solvent. If the same person or agency holds both mortgages he can exercise discretion in protecting the second-mortgage equity.

It is also possible that second mortgages can be made a more effective method of promoting home ownership by providing convenient terms of repayment. While it would probably be the part of wisdom, as suggested above, that the borrower be required to pay off the second mortgage in a shorter period than the maximum allowed for first mortgages under the Federal Farm Loan Act, yet it should be possible to spread the payments over a considerable period. Such payments could be made periodic and on the amortization plan, with privilege of repaying larger amounts on due notice. Mortgages are sometimes given in connection with the purchase of farms on which considerable development work must be done before they can be put on a paying basis. While the work of development is progressing, a mortgage holder could render the farm owner great assistance by deferring all payments, as far as possible, until a paying basis

is reached. In the meantime the value of the security would be increasing as a result of the improvements made. That there is a need for such elements of convenience in second mortgage loans is shown by the number of cases of private loans studied in which provisions of this character occur.

PUBLICATIONS OF THE UNITED STATES DEPARTMENT OF AGRICULTURE RELATING TO FARM CREDIT.

How the Federal Farm Loan Act Benefits the Farmer. (Farmers' Bulletin 792.)

How to Use Farm Credits. (Farmers' Bulletin 593.)

Costs and Sources of Farm Mortgage Loans in the United States. (Department Bulletin 384.)

Factors Affecting Interest Rates and Other Charges on Short-time Farm Loans. (Department Bulletin 409.)

Amortization Methods for Farm Mortgage Loans. (Office of Secretary, Circular 60.)

PUBLICATIONS OF THE FEDERAL FARM LOAN BOARD OF THE UNITED STATES TREASURY DEPARTMENT.

National Farm Loan Associations. (Circular No. 1.)

How Farmers May Form a National Farm Loan Association. (Circular No. 2.)

New Mortgages for Old. (Circular No. 3.)

The Federal Farm Loan Act. (Circular No. 4.)

The Farm Loan Primer. (Circular No. 5.)

Killing Off Mortgages. (Circular No. 7.)

Rulings and Regulations of the Federal Farm Loan Board. (Circular No. 10.)

Amendments to the Federal Farm Loan Act. (Circular No. 11.)

Land Title Registration by Certificate. (Bulletin No. 1.)

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BULLETIN No. 969

Contribution from the Bureau of Animal Industry
JOHN R. MOHLER, Chief



Washington, D. C.

PROFESSIONAL PAPER

October 6, 1921

THE MEXICAN WHORLED MILKWEED (*ASCLEPIAS MEXICANA*) AS A POISONOUS PLANT.

By C. DWIGHT MARSH, *Physiologist in Charge of Investigations of Stock Poisoning by Plants*, and A. B. CLAWSON, *Physiologist, Pathological Division*.

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INTRODUCTION.

Many of the milkweeds are said to have poisonous properties. Definite experiments, however, proving their toxic or nontoxic characteristics have been made in regard to only a few species. Reports by stockmen and others of the poisoning of livestock by these plants have been made from many parts of the Western States, and yet almost an equal number of reports have been made asserting that the plants are harmless. Generally speaking, the reports of harmful results have not indicated clearly what species of milkweed was supposed to be involved. For the most part the plants were not examined by botanists who could determine the species correctly. The United States Department of Agriculture, in making investigations of these cases, has frequently been very much in the dark as to the actual plant suspected and has been led to make experiments on plants which proved to be nontoxic so far as livestock are concerned.

Certain definite and rather startling results, however, have been obtained in the investigation of the whorled milkweeds. As shown in Bulletin 800 of the United States Department of Agriculture,

Asclepias galioides, the whorled milkweed of Colorado, Utah, Arizona, and New Mexico, is one of the most poisonous of the weeds affecting our livestock, and under some circumstances causes very heavy losses. Especial interest, therefore, attaches to the other closely allied plants. The whorled milkweeds form a very distinct group of the milkweed family, *Asclepiadaceæ*, being easily recognized by the narrow leaves which are frequently arranged in a whorled manner.

The number of species of these plants depends upon the opinions of the botanists who study them, but for our purposes four may be recognized which have a fairly definite geographical range. The relationships of these species are briefly characterized by Eggleston in Bulletin 800, United States Department of Agriculture, pages 5 and 6: *Asclepias galioides* is found in Colorado, Utah, Arizona, and New Mexico, west of the Continental Divide, and so far as known does not extend west of Utah; *Asclepias pumila* grows in the plains east of the Rocky Mountains; *Asclepias verticillata* is found in the Mississippi Valley, and eastward; *Asclepias mexicana* is a western species, being especially abundant in California.

In Bulletin 942, United States Department of Agriculture, *Asclepias pumila* and *Asclepias verticillata* var. *geyeri* were shown to have properties similar to those of *Asclepias galioides*, but differing in degree. It is evidently a matter of considerable importance, as well as of interest, to find out definitely the character of *Asclepias mexicana*, which has been frequently reported in California as a sheep-poisoning plant, although published statements are very few.

Chesnut (1898) says that it is reported from California that sheep and calves were poisoned by eating the growing plant, and cows by eating hay containing it.

Pammel (1910) quotes the statement of Chesnut.

Jepson (1911) states that it is said to poison cattle.

Hall (1912) says:

It is much dreaded by sheepmen on hot days, when they are obliged to drive their flocks over dry districts, where there is little other vegetation and no water. Under these conditions the sheep are tempted to eat the milkweed, which contains an active poison and causes many deaths. This is sometimes prevented by cutting the plants down a few days before the sheep are driven through, the object being to dry the herbage and so render it less tempting.

Hall and Yates (1915) speak of the three species, *Asclepias mexicana*, *Asclepias eriocarpa*, and *Asclepias speciosa*, as being equally poisonous, treat of their distribution, and give symptoms as reported to them. These symptoms do not correspond to those appearing in sheep poisoned by *Asclepias mexicana*. It may be noted, too, that the authors of this bulletin have not only failed to get any clear evidence of poisoning by *Asclepias speciosa*, but have also failed experimentally to poison animals by it.

Fleming (1920) gives the dosage by which experimental calves and sheep were poisoned.

Fleming and co-authors (1920) give a somewhat extended account of the plant, with a report of feeding experiments on cattle and sheep.

It seems probable from present investigations that many of the cases of poisoning attributed to *A. speciosa*, *A. eriocarpa*, and *A. fremonti* were really due to *A. mexicana*. No detailed experimental work, however, has been done on *A. eriocarpa* or *A. fremonti*.

DESCRIPTION OF ASCLEPIAS MEXICANA.¹

The following is a technical description of the plant, *Asclepias mexicana* (see Pl. I), known as the Mexican whorled milkweed, also as the narrow-leaf milkweed. The stems are erect, single or several, often branching at base, woody at base, 1 to 6 feet high; main root horizontal, branching, producing adventitious buds; stems glabrous below, slightly short, hairy, and branching above; the leaves in whorls, 2 to 6, sometimes in axillary bundles, linear to narrowly lanceolate, short petioled, 2 to 6 inches long, 2 to 6 lines wide, often folding together, smooth, acute at both ends; flowers usually in corymbose terminal umbels, many-flowered, peduncles much shorter than leaves, and 2 to 3 times as long as the pedicels, which are surrounded by numerous narrow bracts; corymb and flowers short, soft, hairy; flowers greenish-white, sometimes purplish; calyx and corolla turned back after opening; calyx five-cut; corolla deeply five-cleft; crown of 5 hoods, hoods erect, open, containing a linear horn 2 or 3 times as long as the hood, and surrounding the column (united stamens) in which are the 2 ovaries, with slender styles, which unite to the single disklike stigma, the anthers adhering to the stigma and opening on the outside, thus compelling the use of insects or some other outside agency to transport the waxy mass of pollen to the stigma disk; pods from 2 to 3 inches long, smooth, narrow, splitting on the sides, seeds flat, reddish-brown, with a tuft of long hairs at summit. It flowers from June to August.

DISTRIBUTION AND HABITS OF ASCLEPIAS MEXICANA.

The plant ranges from Mexico northward through California, western Nevada, and southern Washington to eastern Idaho, as shown in figure 1.

For central California Jepson (1911) says, "Forming patches in dry ground, common and widely distributed in barren valley fields." It is also a foothill species; in speaking of Nevada M. E. Jones, in an unpublished note, states that it occurs in juniper and oak zones. For the range from northern California to Washington, Howell tells us that

¹ The description of the plant and the account of its distribution were prepared by W. W. Eggleston, of the Bureau of Plant Industry.

"it is found along streams." It follows the valley of the Columbia River and its tributaries into Idaho, where it is occasionally found at an altitude of 6,000 feet. It occurs on the Warner Mountains, Modoc County, Calif., at that altitude, but usually in other parts of the United States it is at much lower altitudes.

Like *A. galioides* it quite plainly thrives best in newly disturbed soil, but there is no evidence that it is spreading as a weed so rapidly as *A. galioides*. In comparison with *A. galioides* it is a larger plant, with wider leaves and flower clusters in a terminal corymb.



FIG. 1.—Distribuion of *Asclepias mexicana* in the United States.

EXPERIMENTAL WORK.

During the summer of 1920, 19 feeding experiments with *Asclepias mexicana* were made. In all cases sheep were used, the material being fed with the balling gun. In 5 cases the whole top—leaves, stems, and flowers—was fed; in 5 other cases leaves and in 9 cases stems were used. The material was obtained through the kindness of Prof. H. M. Hall, of the Carnegie Institution, and was collected at Mount Diablo, Solano, Hollister, and between Newman and Dos Palos, all in California. While dried plant was fed, the dosage is given in terms of green plant for 100 pounds weight of sheep, 75 per cent being allowed for loss in drying.

In Table 1 the experiments with this plant are summarized.



ASCLEPIAS MEXICANA, SHOWING MANNER OF FLOWERING AND THE FRUIT.



FIG. 1.—SHEEP 610. JULY 7, 1.20 P. M.
WEAKNESS IN HIND LEGS, MORE
PRONOUNCED ON ONE SIDE.



FIG. 2.—SHEEP 610. JULY 9, 4.05 P. M.
POSITION AFTER FALLING.



FIG. 3.—SHEEP 610. JULY 9, 4.12 P. M.
STANDING WITH DIFFICULTY.

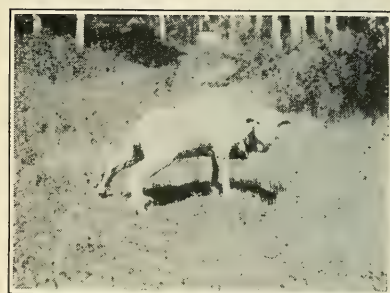


FIG. 4.—SHEEP 610. JULY 10,
9.50 A. M. A CHARACTERISTIC
ATTITUDE WHEN ATTEMPTING TO
STAND.



FIG. 5.—SHEEP 590. SEPTEMBER 1,
8.50 A. M. THE ANIMAL IN A SPASM
IN OPISTHOTONOS POSITION.



FIG. 6.—SHEEP 590. SEPTEMBER 1,
9.10 A. M. THE ANIMAL IN A SPASM.

TABLE 1.—Summary of feeding experiments with *Asclepias mexicana* (air-dried plant fed with balling gun; no remedies used).

Animal.		Date of feeding.	Part of plant used.	Weight of plant estimated as green plant per 100 pounds of animal.	Result.	Place and date of plant collection.
Designation.	Weight.					
	Pounds.	1920.		Pounds.		
Sheep 582....	98	June 21	Leaves.....	0.176	Not sick.....	Mount Diablo, Calif., fall of 1919.
Sheep 588....	93	June 23	do.....	.353	Sickness.....	Solano, Calif., fall of 1919.
Sheep 595....	78	June 28	do.....	.529	do.....	Do.
Sheep 603....	97.75	July 1	do.....	.705	do.....	Do.
Sheep 607....	93	July 6	Stems.....	.705	Not sick.....	Do.
Sheep 610....	81.75	do.....	Leaves.....	.882	Death.....	Do.
Sheep 553....	102.5	July 8	Stems.....	.882	Not sick.....	Do.
Sheep 579....	86	July 13	do.....	1.058	do.....	Do.
Sheep 581....	75.5	July 14	do.....	1.323	Slight sickness.	Mount Diablo, Calif. fall of 1919.
Sheep 584....	82	July 16	do.....	1.411	Not sick.....	Do.
Sheep 586....	128	July 20	do.....	1.764	Slight sickness.	Mount Diablo and Solano, Calif., fall of 1919.
Sheep 595....	81	July 22	do.....	1.481	Not sick.....	Solano, Calif., fall of 1919.
Sheep 568....	86	Aug. 10	Leaves, stems, and flowers.	.882	Sickness.....	Newman, Calif., July, 1920.
Sheep 575....	72.25	Aug. 13	Leaves, stems, and flowers. Large proportion of stems.	1.058	do.....	Do.
Sheep 580....	69	Aug. 23	Leaves, stems, and flowers.	1.235	do.....	Do.
Sheep 590....	103.5	Aug. 31	do.....	1.543	Death.....	Do.
Sheep 595....	92	Sept. 3	do.....	1.323	do.....	Do.
Sheep 602....	93.25	Sept. 9	Stems.....	2.205	Symptoms.....	Do.
Sheep 603....	106.5	Sept. 13	do.....	3.527	Possible symptoms.	Do.

TYPICAL CASE, SHEEP 610.

Sheep 610 was a ewe weighing 81.75 pounds at the time of the experiment. She had not been used in any other experimental work. To this animal was given by the balling gun, between 5.07 and 5.15 p. m., on July 6, 87.75 grams of dry *Asclepias mexicana* leaves, an equivalent of 0.882 pound of green plant per 100 pounds of animal. When observed at 6.25 a. m. July 7 she was unsteady, staggering as she walked about. At 7.20 a. m. the unsteadiness had increased in a marked degree. At 8.59 a. m. her temperature was 105° F., pulse 152, respiration 36. When observed between 1.10 and 1.30 p. m. she could move about without falling, but staggered, and when moving about went with a sidling gait, the weakness being most pronounced in the hind legs. Plate II, figure 1, shows very clearly this weakness in the hind legs. This condition continued during the afternoon and evening. At 5.33 p. m. the temperature was 103, pulse 140, and respiration 44.

On July 8 at 8.30 a. m. she appeared somewhat better than on the preceding day. At 9.36 a. m. the temperature was 102.4, pulse 120,

respiration 40, the pulse being somewhat weak and irregular. During the day her condition remained very much the same, and at night she seemed to be somewhat stronger than in the morning.

On July 9 at 9.22 a. m. the temperature was 102.5, pulse 120, respiration 56. The pulse was rapid, weak, and regular. The animal still was weak and staggered, as in the preceding day. At 4.07 p. m. the sheep was watered, and while being brought in fell and was able to stand only with assistance. When placed in her pen she fell, coming down flat on the ventral surface, with her hind legs stretched out behind. (See Pl. II, fig. 2.) She was able soon to get upon her feet, but stood with difficulty, as shown in Plate II, figure 3. At 4.27 p. m. she was down again in the same position as shown in Plate II, figure 2. At 4.46 p. m. her temperature was 103, pulse 170, respiration 60. Respiration was irregular, and she was unable to stand on her feet very long.

On July 10 at 9.03 a. m. the temperature was 102.1, pulse 140, respiration 80. During the day the animal continued much as on the preceding day, but apparently was somewhat stronger. At 9.45 in the morning she was taken out of the pen and placed in the yard, where she could get at grass, but ate very little. Plate II, figure 4, shows the attitude assumed by the animal. At 4.21 p. m. the temperature was 104.3, pulse 128, respiration 82. At 7.20 p. m. she suddenly fell in a spasm, drawing the head back in a position of opisthotonos and using the legs vigorously. She was unable to get upon her feet until 7.24 p. m., when she stood with legs spread apart, head low and stretched forward. At 7.27 p. m. she stepped back with her head held high, fell over on the left side, groaned, struck her head upon the ground repeatedly, then threw the head back in a clonic spasm followed by a tonic spasm. At 7.33 p. m. she was lying with head partly raised and shaking as if with palsy. At 7.34 p. m. she rose to her feet, but at 7.35 fell with the forefeet spread out. At 7.38 p. m. she was upon her feet again, and was able to stand in a very uncertain way, but was down again at 9.35 p. m., the mouth moving as if chewing. She was somewhat salivated at this time. At 10 p. m. she was still down, but with the head erect, moving from side to side. At 10.15 p. m. she was going through a series of clonic spasms. At 11 p. m. she was dead, having struggled more or less violently just before death.

No good pictures were taken of this animal during the period of spasms, but Plate II, figures 5 and 6, which were taken of Sheep 590, show some of the characteristic attitudes assumed by animals in the stage of spasms. Figure 5 shows very clearly, in the condition of the ground of the corral, how the animal when down goes through a series of motions. This animal differed somewhat from others in that at no time was there an extremely high temperature.

RESULTS OF EXPERIMENTAL WORK AND CONCLUSIONS.

SYMPTOMS.

The symptoms exhibited by poisoned animals paralleled very closely those seen in cases poisoned by the other whorled milkweeds, *A. galioides*, *A. pumila*, and *A. verticillata* var. *geyeri*, differing little except in degree.

There was depression with staggering, the weakness being especially marked in the hind legs. As in the *A. pumila* cases, while standing the animals frequently held the head rather high with the nose extended forward. The pulse was always high and rather weak. These were the only symptoms in the milder cases, if we except a slightly higher temperature.

In the severe cases the stage of weakness was followed by a stage in which there were spasms, mostly clonic, like those exhibited by animals poisoned by *A. galioides*. The animal would throw itself about violently, sometimes showing an opisthotonic position in its spasms, sometimes drawing the head toward the chest. Walking and running movements, while lying on the side, accompany the spasms, and frequently there are convulsive movements of the jaw. Two of the fatal cases were salivated and one was bloated. The animals groan, and in breathing there is frequently a marked interval between inspiration and expiration, the expiration being more or less violent. The temperature rises during the spasms. In Sheep 590 it reached 107.7° F. and in Sheep 595, 106.4° F. These maximum temperatures were taken just after the death of the animals. In this connection it is interesting to note that temperature observations on *A. galioides* showed a decline in temperature before death (Bul. 800, p. 26), while in the *A. mexicana* and *A. pumila* cases (Bul. 942, p. —) the maximum was reached at the time of death. In all whorled-milkweed cases the prognosis of those which pass into the stage of spasms is bad.

Only three of the *A. mexicana* cases showed spasms, and they died. Of the *A. galioides* cases described in Bulletin 800 only one, Sheep 478, recovered after passing into the stage of spasms. Of the sheep poisoned by *A. pumila* only two exhibited spasms, and they died. Only three sheep were poisoned by *A. verticillata* var. *geyeri*; all recovered, and two went into the stage of spasms.

DELAY IN DEVELOPMENT OF SYMPTOMS.

Table 2 shows the time which elapsed before the appearance of symptoms.

The average time of 14 hours and 5 minutes between the time of feeding and beginning of symptoms is probably slightly high. A few sheep showed symptoms when first seen in the morning and may have been sick for some time previously. Then, too, in cases which

come down somewhat slowly, as these do, it is not easy to distinguish the very beginning of symptoms. The shortest time was 12 hours and 45 minutes, occurring in three cases, and they were sick when first observed in the morning following the feeding.

TABLE 2.—Time elapsed between feeding of plant and development of symptoms.

Animal.	Quantity per 100 pounds of animal.	Part of plant used.	Result.	Time elapsing before symptoms.
	Pounds.			H. m.
Sheep 588.....	0.353	Leaves.....	Sickness.....	14 40
Sheep 595 (June 28).....	0.529	do.....	do.....	14 45
Sheep 603 (July 1).....	0.705	do.....	do.....	16 25
Sheep 610.....	0.882	do.....	Death.....	13 10
Sheep 581.....	1.323	Stems.....	Slight sickness.....	15 10
Sheep 586.....	1.764	do.....	do.....	15 37
Sheep 568.....	0.882	Leaves, stems, and flowers..	Sickness.....	14 51
Sheep 575.....	1.058	do.....	do.....	12 45
Sheep 580.....	1.235	do.....	do.....	12 45
Sheep 590.....	1.543	do.....	Death.....	12 55
Sheep 595 (Sept. 3).....	1.323	do.....	do.....	12 45
Sheep 602.....	2.205	Stems.....	Symptoms.....	12 50
Sheep 603 (Sept. 13).....	3.527	do.....	do.....	13 49
Average.....				14 5

The time elapsing before symptoms in *A. galioides* was 14 hours and 6 minutes; in *A. pumila* 16 hours and 17 minutes; and in *A. verticillata* var. *geyeri* 16 hours and 47 minutes.

The average time in all the species of whorled milkweed was much the same. There was, however, much more variation in limits of time in the other species. *A. galioides* varied from 2½ to 21 hours, *A. pumila* from 12 hours and 37 minutes to 30 hours and 15 minutes, and *A. verticillata* var. *geyeri* from 14 hours and 10 minutes to 20 hours and 35 minutes, while *A. mexicana* varied only from 12 hours and 45 minutes to 16 hours and 25 minutes.

A comparison of these figures with those in Fleming and co-authors (1920, pages 15 to 17), shows a good agreement in averages. In Table I on feeding of green plant the average time from feeding to symptoms was 15 hours and 27 minutes. The combined average of Tables II and III of feedings of dry plant was 14 hours and 48 minutes. This latter average is obtained on the assumption that the time of feeding of Sheep No. 8 was probably 2.50 p. m. instead of 2.50 a. m., as given in the Nevada bulletin.

There is, however, a wider range of variation than in the work at the Salina Experiment Station, the minimum being 1 hour and 50 minutes, and the maximum 23 hours and 20 minutes. The large maximum figures are doubtless explained, in part at least, as stated in the Nevada bulletin, by the fact that no night observations were made, so that in many cases the time of the beginning of symptoms was not noted. The minimum figures in most cases are correlated with very heavy doses.

DURATION OF SICKNESS.

Table 3 shows the length of time the sickness continued in cases which recovered. The times were computed from the first symptom noted to the last. The actual periods of illness doubtless were somewhat greater, for as the animals were not generally under constant observation neither the beginning nor the ending of sickness would be recorded with much accuracy. The figures, however, will give a good general idea of the duration of illness and can be compared with the results in the other whorled milkweeds, as they were obtained in the same manner.

TABLE 3.—Duration of sickness in cases of recovery.

Animal.	Duration of symp- toms.	Animal.	Duration of symp- toms.
	H. m.		H. m.
Sheep 588.....	50 10	Sheep 568.....	95 54
Sheep 595.....	48 20	Sheep 575.....	73 45
Sheep 603.....	48 1	Sheep 580.....	74 6
Sheep 581.....	7 30	Sheep 602.....	5 40
Sheep 586.....	7 54	Sheep 603.....	(1)

¹ One observation only.

Of the three animals that died, Sheep 610 was sick 89 hours and 35 minutes; Sheep 596, 14 hours and 56 minutes; and Sheep 595, 15 hours and 15 minutes.

The shortest period of illness was in Sheep 602—5 hours and 40 minutes—and the longest in Sheep 568—95 hours and 54 minutes. As in other whorled-milkweed cases the symptoms continued longest in the more pronounced cases.

The average period of sickness was 45 hours and 42 minutes.

It was shown in Bulletin 942, United States Department of Agriculture, pages 12–13, that the average period of sickness in sheep poisoned by *A. galioides* was 4 hours and 39 minutes; by *A. pumila* it was 48 hours; and by *A. verticillata* var. *geyeri* it was 56 hours.

It is evident that the period of sickness in the *A. mexicana* cases corresponded fairly well to that found for *A. pumila* and *A. verticillata* var. *geyeri*, and like them differed widely from the *A. galioides* cases.

In the experiments of Fleming and co-authors (1920) the average duration of sickness in the sheep that recovered, as given in Tables I, II, and III, was 39 hours and 37 minutes, while in the cattle as given in Tables VII and IX it was 34 hours and 1 minute.

AUTOPSY FINDINGS.

Autopsies were made upon the three animals that died. Two of the three were bloated. The lungs were congested in all. In two the thymus was congested, and in the third there were petechiae in this organ. Petechiae were present on the hearts of two.

In one animal congestion was present in the duodenum, jejunum, and ileum; in another this condition was found only in the ileum and cecum; while the third had a hemorrhagic area in the duodenum and minute hemorrhages in the ileum. The pancreas was congested in one. The livers of two were noted as pale. The kidneys were congested in one and hyperemic in another.

In general, the autopsy findings corresponded very well to those seen in animals poisoned by the other whorled milkweeds.

PATHOLOGICAL CHANGES IN TISSUES.

The autopsies in 2 of the 3 sheep killed with *Asclepias mexicana* in 1920 were commenced within 30 minutes after their deaths. These were Sheep 590 and 595. Sheep 610 was dead much longer before the autopsy and well-marked post-mortem changes had occurred in the tissues. The following description of the pathological changes is based on Nos. 590 and 595. The material was fixed in 10 per cent formalin and stained with Delafield's hematoxylin and eosin, except specimens of the cerebellum of Sheep 590, which were fixed in alcohol and stained with various nerve-cell stains. Formalin-fixed material of the cerebellum of both sheep was stained with toluidin blue, Nissl stain, polychrome methylene blue, neutral red, and other stains.

Liver.—The hepatic cells in both animals had undergone well-marked degenerative changes which differed slightly in the two cases—those of Sheep 590 were very fatty, the nuclei, however, taking the stain well, while the hepatic cells in the liver of Sheep 595 had a very granular and swollen cytoplasm. In the liver of Sheep 595, too, certain hepatic cells, singly and in groups, showed marked affinity for eosin. In the capillaries of the liver lobules of both there was an unusually large number of leucocytes, especially polymorphonuclear. These were often in small clumps, covering the area of half a dozen or more hepatic cells in the liver section of Sheep 590.

The livers of both animals had congested and edematous areas with some small hemorrhages. This was most noticeable in one preparation of the liver of Sheep 590, where the congestion was severe just beneath the capsule and had compressed the liver cords.

Many veins, both portal and hepatic, were empty, while others contained much granular detritus, brownish pigment granules, degenerate erythrocytes, and sometimes endothelial cell nuclei and numerous leucocytes. Rarely hepatic cells were found in the sublobular veins. The wall of the congested portion of the common bile duct in both cases had undergone necrotic changes extending well into the mucosa. The epithelial layer was gone.

Kidneys.—In both kidneys there was congestion of the straight veins of the medulla and areas of capillary congestion in the cortex with a few small hemorrhages between the tubules. The principal

change had occurred in the epithelial cells of the convoluted tubules and consisted of cloudy swelling. Other cells were present, singly and in groups, the cytoplasm of which had an unusual affinity for eosin. Such cells contained shrunken nuclei which stained darker and more uniformly than normal. Other nuclei were very faint or had entirely disappeared. The lumina in many places contained a considerable quantity of disintegrated cytoplasm and sometimes free epithelial cell nuclei. In congested areas frequently epithelial cells of the tubules contained considerable brownish granular pigment. Granular material, pigment, and an abnormal number of leucocytes were found in some veins. Some distended capillaries in the sections from the kidneys of Sheep 595 were occupied by hyalin areas which stained strongly with eosin.

Other tubules than the convoluted, as the ascending limb of Henle, showed similar though less pronounced changes.

Heart.—The myocardium of the left ventricle showed changes like those occurring in some of the *A. galioides* cases, but were not so marked. In many areas the capillaries were distended with blood and very prominent between the muscle fibers. The tissue was mildly edematous. In most areas the muscle fibers had a less distinct cross-striated appearance and a more granular cytoplasm than normal. A few minute hemorrhages appeared. Very few leucocytes were present. The red blood corpuscles stained well and appeared to be normal.

Lungs.—There was a mild inflammation of the lungs. The capillaries were engorged and distended, in many places nearly filling the alveoli. Numerous leucocytes, mostly polymorphonuclear, were scattered throughout the tissue. Many epithelial cells of the alveoli appeared swollen or vacuolated and their nuclei were irregular in outline. The epithelial cells of the bronchioles were swollen or in the process of disintegration, the bronchioles containing much granular material, many nuclei of exfoliated cells, and sometimes erythrocytes.

In some veins there were areas composed of normal and pale erythrocytes, much finely granular material, and a considerable number of leucocytes, mostly polymorphonuclear. A considerable quantity of brownish pigment was distributed throughout the sections.

Thyroid.—Little that was abnormal was found in the thyroid glands. This organ was not congested in either animal, though some brownish pigment and pale erythrocytes were found. In a few capillaries the erythrocytes appeared to have fused, forming hyalin thrombi. In the *A. galioides* cases this gland was almost always severely congested.

Thymus.—Congestion had occurred in the thymus in each of the two sheep, though this was most pronounced in the thoracic portion of the gland of Sheep 595, where extensive hemorrhage into the

glandular tissue had occurred, especially into the medullary portion of the lobules. Around some blood vessels in the thymus of Sheep 595 there were many large, coarsely granular cells, which had a strong affinity for eosin. These closely resembled eosinophiles, except that many were rather large and had nuclei almost circular in outline. The lymphoid cells appeared to be normal. Some brownish pigment was present, and in a few small veins in Sheep 590 the erythrocytes appeared as though fused.

Spleen.—In the specimen from the spleen of Sheep 590 there were small areas of congestion in the splenic pulp. The samples from Sheep 595 contained very little blood. In both cases some brownish pigment was present, and in the tissue from Sheep 590 some cavernous veins contained pale and disintegrated erythrocytes.

Lymph glands.—A mesenteric lymph gland and a small group of hemolymph nodes from Sheep 590 were studied. There was no indication of an effect on lymphoid cells, but some erythrocyte destruction was apparent. In the lymph gland many endothelial cells contained ingested erythrocytes in various stages of destruction. In the hemolymph nodes there were areas where practically all erythrocytes stained very poorly.

Alimentary tract.—Specimens from the abomasum, duodenum, jejunum, ileum, and cecum were studied. There was a well-marked infiltration of leucocytes into the mucosa of the various portions of the small intestine and the one sample of cecum examined. These were of the polymorphonuclear and plasma cell types. Congestion accompanied with diapedesis of erythrocytes and edema was present in some places, and in all portions of the small intestine the villi and that portion of the mucosa next the lumen of the intestine were more necrotic than one would expect in an animal that had been dead so short a time.

The glandular epithelial cells were swollen and many small nuclei, probably of leucocytes, were very commonly lying in the epithelial layer and sometimes in the lumen of the gland. Many such nuclei were degenerated. In places the veins contained pale erythrocytes, granular material, and sometimes a fibrinlike network and numerous leucocytes.

The lymph nodes of the ileum of Sheep 590 were edematous and contained an unusual number of phagocytic cells, which had ingested erythrocytes and pigment or partially digested granules of nuclear material.

Nervous tissue.—Specimens of cerebrum, cerebellum, medulla, and cervical and lumbar portions of the spinal cord were examined. None of these was severely congested, though minute hemorrhages were formed in various places. These were presumably due to diapedesis of the red corpuscles, as ruptured vessels were not found. In most hemorrhages the erythrocytes were confined to the perivascular

lymph space, but in some instances they had penetrated into the surrounding tissue. Pericellular lymph spaces, in many if not most instances, were enlarged. The nerve cells had undergone fatigue changes similar to those found in the *A. pumila* and *A. galioides* cases. This consisted in a breaking up of the Nissl bodies or a marked reduction in the chromatin content of the cell.

In general the pathological conditions of the *A. mexicana* cases are the same as those found in *A. galioides* and *A. pumila* poisoning, and consist mainly of capillary congestion and degenerative changes in certain tissues. Areas of congestion were found in the liver, kidneys, heart, muscle, lungs, thymus, and mucosa of portions of the intestines. The cells of the liver, kidney tubules, heart muscle, intestinal glands, and certain nerve cells showed degenerative changes which may probably be accounted for by excessive functional activity. Fatigue effects were most apparent in the heart-muscle fibers and nerve cells. The presence of an abnormal number of leucocytes in the liver, intestinal mucosa, and lungs is probably due to the degenerative changes of the tissue cells.

Degeneration of hepatic cells, epithelium of kidney tubules, and intestinal mucosa appears to be more pronounced in the *A. mexicana* cases than in those animals killed by *A. galioides*. On the other hand the degeneration and capillary congestion of heart muscle, congestion of the nervous system, and fatigue effects on the Purkinje cells of the cerebellum were much more pronounced in the *A. galioides* cases.

The changes found in the tissues of the *A. pumila* cases correspond very closely to those described for the *A. mexicana* cases. The effects of these two species of plants would appear to be practically the same, but those produced by the more toxic *A. galioides* differ slightly in degree.

TOXIC AND LETHAL DOSES.

The balling gun was used in all the experimental work from which the dosage was computed, so that the animals probably received the material in a somewhat shorter time than they would when feeding on the range. It would be expected on this account that under range conditions the dosage, in the majority of cases, would be larger.

Whole plant.—Table 4 shows the dosage when the animals received the whole plant.

TABLE 4.—Dosage of *A. mexicana*, whole plant.

Animal.	Quantity fed per 100 pounds of animal.	Result.	Animal.	Quantity fed per 100 pounds of animal.	Result.
	<i>Pounds.</i>			<i>Pounds.</i>	
Sheep 568.....	0.882	Sickness.	Sheep 590.....	1.543	Death.
Sheep 575.....	1.058	do.	Sheep 593.....	1.323	Do.
Sheep 580.....	1.235	do.			

The minimum lethal dose for these animals was 1.323 pounds. This is probably a rather accurate figure, for Sheep 575 received 1.058 pounds and Sheep 580 1.235 pounds without fatal results in either case. The minimum toxic dose was 0.882 pound. No experiments were made with slightly smaller doses, but as Sheep 568 was a mild case this dose must be not far from the minimum of toxicity.

Leaves.—Table 5 shows the dosage when leaves only were fed.

TABLE 5.—*Dosage of A. mexicana, leaves only.*

Animal.	Quantity fed per 100 pounds of animal.	Result.	Animal.	Quantity fed per 100 pounds of animal.	Result.
	<i>Pounds.</i>			<i>Pounds.</i>	
Sheep 582.....	0.176	Not sick.	Sheep 603.....	0.705	Sickness.
Sheep 588.....	0.353	Sickness.	Sheep 610.....	0.882	Death.
Sheep 595.....	0.529	do.			

As Sheep 603 was not very sick on 0.705 pound, it is probable that 0.882 pound, which caused the death of Sheep 610, is close to the lethal dose. While 0.353 pound was the smallest dose producing sickness, it is possible that it is not the minimum, as there were no tests between that and 0.176 pound which was given without effect to Sheep 582.

Stems.—Nine sheep were fed on stems from which all leaves had been removed, as shown in Table 6.

TABLE 6.—*Dosage of A. mexicana, stems only.*

Animal.	Quantity fed per 100 pounds of animal.	Result.	Animal.	Quantity fed per 100 pounds of animal.	Result.
	<i>Pounds.</i>			<i>Pounds.</i>	
Sheep 607.....	0.705	Not sick.	Sheep 586.....	1.764	Slight sickness.
Sheep 563.....	0.882	do.	Sheep 595.....	1.481	Not sick.
Sheep 579.....	1.058	do.	Sheep 602.....	2.205	Symptoms.
Sheep 581.....	1.323	Slight sickness.	Sheep 603.....	3.527	Possible symptoms.
Sheep 584.....	1.411	Not sick.			

The smallest quantity of stems fed which produced symptoms was 1.323 pounds. As compared with this, Sheep 584 and Sheep 595 showed no effect from 1.411 pounds and 1.481 pounds, respectively. The table shows also that as much as 3.527 pounds was fed to Sheep 603 with only slight effect. No animals were killed by the feeding of stems. It appears then that as little as 1.323 pounds may produce slight symptoms. The lethal dose has not been determined, but it probably is several times this quantity.

For comparative purposes the toxic and lethal doses of whole plant, leaves, and stems to 100 pounds of animal may be tabulated as follows:

	Minimum toxic dose. <i>Pounds.</i>	Minimum lethal dose. <i>Pounds.</i>
Leaves.....	0.353	0.882
Whole top.....	0.882	1.3
Stems.....	1.323	More than..... 3.5

It is evident that the toxic principle of the plant is found very largely in the leaves.

A comparison of the preceding figures with the toxic and lethal dosages for sheep given in Nevada Bulletin 99 can be made by reducing the dosage in Table I, page 15, of the Nevada bulletin to pounds per hundredweight of animal. It will be seen that the smallest toxic dose, 0.537 pound per hundredweight in the case of Sheep 25, is somewhat smaller than the figures obtained in our experiments. It may be noted, too, that Sheep 75 received 0.555 pound without effect and that the smallest lethal dose was 2.3 pounds in the case of Sheep 6.

If the data of Table II of the Nevada bulletin giving the feedings of air-dried plant are similarly reduced to a dosage for 100 pounds of animal and an allowance of a loss of 75 per cent by evaporation is made, as in our work, the smallest lethal dose would be 2.059 pounds in Sheep 72 and the smallest toxic dose 1 pound in Sheep 59.

The dosage in Table III (Nevada) of material which had dried in the field is somewhat larger, the lethal dose, 7.5 pounds in Sheep 43, being especially large. This is probably accounted for by the fact that there had been some loss of leaves in the field, for it is shown on page 14 of this paper that the leaves are especially toxic.

Table 7 shows the comparative toxicity of the different whorled milkweeds:

COMPARATIVE TOXICITY OF SPECIES OF WHORLED MILKWEED.

TABLE 7.—Comparative toxicity of different species of whorled milkweed.

Species.	Minimum toxic dose of whole plant.	Minimum lethal dose of whole plant.	Minimum toxic dose of leaves.	Minimum lethal dose of leaves.	Minimum toxic dose of stems.
	<i>Pounds.</i>	<i>Pounds.</i>	<i>Pounds.</i>	<i>Pounds.</i>	<i>Pounds.</i>
<i>A. mexicana</i>	0.882	1.323	0.353	0.882	1.323
<i>A. galioides</i>	0.22	0.22	0.138	0.138	1.543
<i>A. pumila</i>	0.787	2.165			
<i>A. verticillata</i> var. <i>geyeri</i>	2.205		1.286		

While too much reliance must not be placed on this table as showing exact relationships, nevertheless it indicates, in a general way, the relations between the species. So far as the whole plant is concerned, *A. mexicana* and *A. pumila* are about equally toxic. *A. galioides* is 4 times as toxic as these two species and 10 times as toxic as *A. verticillata* var. *geyeri*. As regards the lethal dose of the whole plant, *A. galioides* is 6 times as toxic as *A. mexicana* and 9.84 times as toxic as *A. pumila*.

With relation to the leaves, *A. galioides* and *A. verticillata* var. *geyeri* compare much as in the whole plant; that is, in a ratio of about 1 to 10. The ratio of *A. galioides* to *A. mexicana*, however, is 1 to 2.56 instead of 1 to 4, as in the whole plant, while the lethal dose is in

the ratio of 1 to 6. There is an apparent anomaly in the dosage of the stems in that the much more poisonous *A. galioides* requires a slightly larger dose than *A. mexicana*. This may be explained in part by the fact that the stems of both plants are only slightly toxic, but there is also some reason for thinking that the chemical study of these plants, the results of which will be published later, will offer an adequate explanation.

ANIMALS AFFECTED.

The experiments reported in this bulletin were on sheep only. Fleming and his co-authors (1920) have shown that cattle are poisoned with a somewhat similar dosage. From the fact that *A. mexicana* produces effects strictly comparable with those caused by *A. galioides* and that it has been shown in a previous paper (U. S. Department of Agriculture Bulletin 800) that *A. galioides* poisons horses as well as sheep and cattle, it is fair to conclude that *A. mexicana* will have the same effect.

SUMMARY.

Asclepias mexicana (the Mexican whorled milkweed), a plant growing on the Pacific slope, and especially in California and Nevada, has long been considered a stock-poisoning plant, particularly dangerous to sheep; but there has not been definite knowledge of the symptoms produced by it or of its toxic dosage.

It produces effects very similar to those produced by the other whorled milkweeds, *A. galioides*, *A. pumila*, and *A. verticillata* var. *geyeri*.

In toxicity *A. mexicana* is about equal to *A. pumila* and about one-fourth as toxic as *A. galioides*. The lethal dose is six times that of *A. galioides*, but about one-half that of *A. pumila*.

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MANUFACTURE OF COWS'-MILK ROQUEFORT
CHEESE.

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Restricted importations of foreign cheese during the war period increased the price of these products and created a demand for information concerning their manufacture. Numerous attempts have been made to manufacture, in the United States, some varieties of foreign cheese, of which 63,000,000 pounds were imported by this country during 1914. Success has attended the making of some of these kinds of cheese; attempts to make others have resulted in absolute failure.

For several years the Dairy Division, Bureau of Animal Industry, conducted experimental work to develop a method of manufacture whereby at least one of the green-mold varieties of cheese, all of which bring high prices, could be made in the United States. As a result of the work this paper gives information on the manufacture of domestic Roquefort cheese from cows' milk, likewise some of the difficulties that may be encountered in manufacturing cows'-milk Roquefort cheese.

Roquefort is one of the highest-priced cheeses on the American market. It is a French mold-ripened cheese made from sheep's milk and has been known for 20 centuries. Pliny,¹ in his book on natural history, referred to this cheese, or cheese of this type, as

¹ Pliny L'Ancien (Pliny the Elder). *Histoire naturelle*, Book XI, chapter 97 (42).

the "cheese most esteemed at Rome." Marcorelle² states that this cheese was used by peasants of France in their ceremonial repasts as long ago as 500 A. D.

There are two other varieties of mold-ripened cheese which are commercially important—the Gorgonzola, of Italy, and the Stilton, of England. Before the war Gorgonzola sold on American markets at practically the same price as Roquefort. Both Stilton and Gorgonzola are made from cows' milk. They are ripened with a mold similar to, if not identical with, that of the Roquefort and are skewered many times to allow air to gain access to the interior and thereby increase the development of the needful mold. The Gorgonzola, like Roquefort, is ripened in caves at a low temperature and is somewhat similar to Roquefort in flavor, texture, and composition, whereas the Stilton is a much drier cheese and is ripened with little or no refrigeration. While these cheeses resemble Roquefort in many respects, Roquefort is generally acknowledged to be the best of the three.

THE MANUFACTURE OF IMPORTED ROQUEFORT.

Almost the entire world's supply of Roquefort cheese comes from Aveyron, in southern France. The cheese is made principally of sheep's milk, although an admixture of cows' milk even there is acknowledged. All the milk used for this cheese is produced and made up into cheese within a radius of 50 miles of the small town of Roquefort, to which it is sent to be cured in the caves. There, too, are the headquarters of several firms that largely control the sale of the world's supply of this cheese. Sheep have been bred for centuries in the vicinity of Roquefort for making the cheese, and it is not uncommon for one sheep during a six-months' period of lactation to produce milk enough to make 35 or 45 pounds of cheese. In 1908 the milk from 450,000 of these sheep produced 19,845,000 pounds of cheese.³ It is doubtful whether such a milking strain of sheep can be found in the United States, especially in sufficient numbers to warrant the establishment of a similar industry in this country.

The caves in Roquefort are of a peculiar rock formation in which there are caves and grottoes connected with one another and with the outside by numerous channels. Through these moist channels there is a vigorous circulation of air, causing a low temperature as a result of rapid evaporation. The temperature and humidity of the caves remain quite constant the year round, and these natural con-

² Art de faire le beurre et les meilleurs fromages. 1833. Anderson, J., and others.

³ Lebrou, P., Les applications du froid en Aveyron à la préparation des fromages de Roquefort. Pp. 424, II. In 2d Internat. Cong. Refrig. Industries, Vienna, 1910.

ditions, together with the ventilation, are favorable to mold growth and to the ripening of Roquefort cheese. At Grove City, Pa., insulated curing rooms have been constructed which are provided with certain conditioning apparatus and refrigeration which make it possible to approximate the conditions found in the caves of Roquefort. As the ideal conditions for making this cheese have been approached, many of the discouraging aspects of the problem have been eliminated. Prevention of desiccation, oversalting and undersalting, proper growth of interior and exterior molds, proper flavor and texture, all appear to be more or less dependent upon supplying and regulating the proper curing conditions. By the use of such equipment considerable cows'-milk Roquefort cheese of good quality has been made and successfully marketed.

COMPOSITION AND CHARACTERISTICS OF ROQUEFORT.

The literature shows a great variation in the composition of Roquefort cheese. The composition as given by Duclaux is in accord with that of Dox, formerly of the Dairy Division.

TABLE 1.—*Total composition of an excellent Roquefort cheese, according to Duclaux.*¹

Substance.	Quantity.
	<i>Per cent.</i>
Casein.....	20.00
Fat.....	35.18
Salt (NaCl).....	4.21
Other mineral salts.....	1.77
Water.....	38.84

¹ Maturation des fromages à basse température, 1901.

TABLE 2.—*Average composition of ripe Roquefort, with respect to fat, water, and salt.*

Substance.	Quantity.
	<i>Per cent.</i>
Fat.....	20 to 36
Water.....	38.5 to 41.
Salt (NaCl).....	3.5 to 4.5.

Several samples of Roquefort cheese of the highest quality were selected and analyzed by Dox.⁴ The composition was as follows:

TABLE 3.—*Composition of highest quality Roquefort cheese.*

	Water.	Fat.	Protein.	Ash.	Salt (NaCl).
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Average.....	38.69	32.21	21.39	6.14	4.14
Minimum.....	37.49	31.50	19.14	5.18	3.64
Maximum.....	40.10	33.53	23.06	6.81	4.88

⁴ Dox, A. W., Die Zusammensetzung des echten Roquefort-Käses. In Ztschr. f. Untersuchung. Nahr. u. Genussmitl., v. 22, no. 4, pp. 239-242. 1911.

There is a remarkable uniformity of composition in the best grades of this cheese. Good Roquefort should contain close to 40 per cent water, 4 per cent salt, and 32 per cent fat. Special significance is attached to the salt-and-water content of the cheese, and the composition of the domestic cheese has been made to approximate as closely as possible that of the imported cheese.

Size.—Roquefort cheese is round, about 7 inches in diameter, and $4\frac{1}{2}$ inches high. Such a cheese should weigh from 4 to 5 pounds.

Surfaces.—There is no definite rind on the ripe Roquefort cheese. The softening of the cheese is due to the mold enzymes and to inclosing it in tin foil, which tends to make the texture of the cheese uniform throughout. As the cheese on the market is wrapped in foil it always appears to be moist, rather than either wet or dry. The surface of the cheese is more or less uneven as a result of punching and scraping.

Odor and color of surface.—The odor of the cheese is not likely to be offensive unless it is too wet or has been kept too long at a high temperature. The color should be slightly orange and never dark.

Mold.—The most conspicuous characteristic of a cut Roquefort cheese is the green mold. This and the *Streptococcus lacticus* have been found to be the chief ripening agents of the cheese.⁵ The cheese presents a marblelike appearance of green and white with luxuriant patches of the mold here and there, but more especially near the mechanical holes which occur more often near the center than near the outer edge. Radiating and ramifying veins of mold extend from the central portion of the cheese to within an inch or so of the outer edge, where there is little or no mold development. Possibly this is due to a higher concentration of salt near the outer edge during the period of mold growth, resulting in a dryer layer as compared with the interior. Ordinarily the mold is bright in color, but where the ripening has been carried to an advanced stage it takes on a darker hue. This is especially true when the mold is subjected to a vigorous oxidation. The mold in the trail of the piercing needle is often of a darker color than that in the cheese a short distance from this point, where the air can not penetrate so readily. The color of the mold in a freshly cut domestic Roquefort cheese which has been held at a low temperature for a long period may have nearly disappeared. In the course of a few minutes, however, upon exposure to the air, the normal green color of the mold gradually returns.

Saltiness.—The saltiness of Roquefort cheese is quite characteristic and is more noticeable when the cheese is fresh than when the flavor has been fully developed. It is the most salty soft cheese on

⁵ Evans, Alice C., Bacterial flora of Roquefort cheese. In Jour. Agr. Research, p. 232. (Vol. XIII, No. 4. Apr. 22, 1918.)

the market. To many this quality is not pleasant, and yet it is doubtful whether Roquefort cheese can be successfully ripened without a high percentage of salt in it. Other conditions being the same, the higher the percentage of salt the slower the ripening, and vice versa.

Defects.—The most common defects of Roquefort cheese made from cows' milk are: The high moisture content, too little or too much salt, the lack of mold, the lack of piquancy, and a color which is too yellow. Cheese is not likely to become waxy and tough unless it has been subjected to excessive ventilation and to too low a relative humidity. Cheese which is gassy sometimes develops offensive flavors, possibly due to an excessive oxidation of the fat. Roquefort is quite soft as compared with other cheeses, and as a result the surfaces and edges are quite easily broken by handling during the curing process.

One of the essential qualities of a Roquefort cheese is that the color be white rather than yellow. The natural color of sheep's milk is white rather than yellow. Marre speaks of it as having "a fine white color."⁶ "The cheese is too yellow" has been the most common criticism of cows'-milk Roquefort.

Because of cheaper milk the cows'-milk Roquefort cheese upon which the data in the bulletin are largely based was made during the months of June and July, rather than in the winter months, when the natural color of the milk is more white. In the experimental work at Grove City more attention has been given to the considerations of flavor, mold, salting, etc., and less attention to color, which seemed of minor importance. Experience in marketing, however, has shown that color is of much greater importance than had been anticipated.

From chemical analysis there is reason to believe that not a great deal of fat is removed in the manufacture of Roquefort, although authorities agree that some of the fat is removed. Marre, in this connection, states that the sheep's milk should preferably be partially skimmed, and that unless this operation is carried to the extreme the quality of the cheese is not appreciably impaired, while the drainage of the curd is favored. Without this procedure the cheese, which should be white and light, will be yellowish, compact, and dense as glue.⁷ On the other hand, a milk skimmed too much gives a dry curd, without adherence and without flavor.

Flavor.—A salty and piquant flavor is the chief characteristic of this cheese and allied blue-mold cheeses of this group. A good cheese should be sapid, sweet, and fragrant. A Roquefort cheese should not have a strong, pungent flavor. This condition may

⁶ Marre, E., *Le Roquefort*, p. 80.

⁷ Marre, E., *Le Roquefort*, p. 95.

develop when the cheese has been subjected to long exposure to the air or when held at too high a temperature. In general, the lighter the color of the mold the milder the flavor of the cheese.

Texture.—Roquefort cheese should not be compact, like Cheddar cheese. Numerous mechanical holes should be made throughout the cheese. A few gas holes may not be harmful, but too many should be avoided. Even the best of the imported cheeses almost always have a number of small gas holes. The mass of the cheese should be friable, soft, and unctuous; yet it should be firm enough to retain its shape, even when held at a high temperature. The cheese when fully ripe should not appear tough and waxy, as in the case of certain other green-mold cheeses.

COMPOSITION OF SHEEP'S MILK.

The percentage composition of sheep's milk in the Roquefort region, as given by Marre,⁸ is quite different from that of cows' milk.

TABLE 4.—*Per cent composition of sheep's milk in the Roquefort region.*

	Water.	Casein.	Fat.	Lactose.	Ash.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Variation.....	76 to 83	5 to 8	5.5 to 10.5	4 to 5	0.8 to 1.2
Average.....	79.5	6.5	8.0	4.5	1.0

Work with sheep's milk has revealed the fact that the acidity of the fresh milk when titrated with phenolphthalein is usually more than 0.2 of 1 per cent, and in contrast with cows' milk gives a much firmer jellylike curd when acted upon by rennet. An examination of the composition of sheep's milk and cows' milk shows that the former has about twice the essential solids of fat and casein that the latter has, yet the ratio of fat to casein in both cases is approximately the same. Rich milk seems somewhat more desirable than poor milk in giving a firm curd when it is set with rennet. Milk testing about 4 per cent has given good results.

THE MANUFACTURE OF COWS'-MILK ROQUEFORT.

In general it has been found to be advantageous to follow the method of making this cheese as outlined by Marre. Because of the difference in the nature of cows' milk and sheep's milk, however, some modification of the process seems advisable.

Acidity.—Fresh, clean milk is essential in making Roquefort. An overripe milk is likely to result in a gassy cheese and may produce a very objectionable flavor. The milk on setting should have an initial acidity of 0.21 to 0.23 per cent. About 3 or 4 per cent of starter is

⁸ Marre, E., *Le Roquefort*, p. 82.

recommended. Sometimes it may be desirable to add the starter to the milk and then ripen the milk to the desired point. There is no indication in the literature that a starter is used in the making of the sheep's-milk cheese. Small variations in the acidity will not cause disastrous results.

Temperature.—Marre advises a temperature of from 24° to 28° C. (76° to 82.4° F.) for setting sheep's milk. For the making of cows'-milk Roquefort a temperature of from 82° to 85° F. is the most desirable. With cows' milk a lower temperature is likely to result in a soft and mushy curd which fails to drain properly. Too high a temperature may make a tough curd.

Setting and rennet.—The milk is warmed in an ordinary 5,000-pound Cheddar-cheese vat and then is stirred to insure an even distribution of the fat. Standardized commercial rennet has been used always with good results. On a basis of 1,000 pounds of milk 3 or 4 ounces (90 to 120 c. c.) of rennet are used. The use of too little rennet may result in an incomplete coagulation, with excessive losses of both fat and casein in the whey. As is customary in making other kinds of cheese, the rennet should be diluted in cold water before it is added to the milk, after which the whole should be carefully stirred.

Cutting.—According to the French method the cheese is cut into lozenges about the size of a walnut and after standing for 10 minutes the curd is removed by means of a scoop and emptied upon the drain cloths. In making the cows'-milk cheese the curd is cut both ways by means of a $\frac{5}{8}$ -inch Cheddar knife. As the curd is being transferred to the drain cloths by tin scoops it is cut crosswise so that the resulting pieces are five-eighths of an inch square by 2 or 3 inches long. If the curd is cut into larger pieces it is more easily broken and, besides, does not expel the whey so readily. Differences in the natural firmness of the curd of the sheep and that of the cow seem to make this change advisable.

Curdling time.—The setting period varies from 1 to 1½ hours, according to the acidity, temperature, and quality of the milk. At first beads of whey, then a thin film of whey, gradually spreads over the surface of the curd, indicating that it is ready to cut. By this time the curd gradually contracts and tends to draw away from the side of the vat. At this period the coagulum should be firm and porcelainlike and should cut readily under the edge of the knife. When the curd has set too long, it is not so readily cut, but pushes along ahead of the knife. There should be no contraction of the curd or unevenness anywhere upon the surface, aside from where it is in contact with the vat. No hard and fast rule can be laid down as to the time of cutting, as so much depends upon the condition of the milk, temperature, and acidity.

Draining the curd.—An adjoining Cheddar-cheese vat of capacity similar to that of the setting vat has been found an excellent substitute for a draining wagon. A skeleton framework is placed in the bottom of the vat and covered with strong cheesecloth. The setting and draining vats should be placed close enough together to permit two or three workers to do the dipping. Large tin scoops holding 1 or 2 gallons each are suitable for this purpose.

The transferring of the curd should be done rapidly and carefully, and two persons working rapidly should dip 3,000 pounds of milk in from 25 to 30 minutes. The whey should be withdrawn from the vat and run through a whey separator. In draining the curd it has been found helpful to raise the cloths from time to time in order to aid the exudation of whey and to bring the curd to the proper condition of dryness. In making the French cheese much emphasis is placed on keeping the curd warm and holding it at an even temperature, and for this reason the curd is frequently turned by means of a short-handled ladle. No difficulty has been encountered at Grove City from having the curd become too cold.

Fat losses.—Fat losses in experimental work have averaged from 0.2 to 0.3 per cent. On a larger scale the fat losses almost always are below 0.3 per cent.

Time of draining.—The time required for draining is ordinarily from 20 to 30 minutes, depending upon how often the cloths are manipulated during drainage. The curd should be placed in the forms in a fairly moist condition. When the curd is too dry, the surface of the cheese is not smooth and compact and may offer an avenue whereby undesirable organisms may gain access to the interior of the cheese. When the surface of the cheese is not smooth, greater losses are sure to occur later in the curing process. Results from many experiments indicate that there is no advantage or disadvantage in using a longer or a shorter period for drainage.

Hoops.—The hoops or forms for cows'-milk Roquefort are round, open, and are $7\frac{3}{8}$ inches in diameter and 6 inches high. Each hoop has six rows of holes running around the form and there are twenty-five $\frac{1}{8}$ -inch holes in each row. The hoops are considerably higher than the cheese itself. The forms are made of galvanized metal with wired edges.

Forms are placed conveniently close to one another upon a special reed matting. The size of the mats is 10 by 34 inches and they rest upon boards of nearly the same size. With mats of this size three cheeses are needed to fill one board. Cloths may be substituted for matting, although the matting is preferable. Before using, all mats as well as boards should be placed in a vat of boiling water. This procedure tends to reduce the number of foreign molds which may cause losses later in the curing process.

FILLING THE FORMS AND ADDING THE MOLD CULTURE.

At the time the curd is put into the forms it is a white, pulpy mass, from which but little whey exudes as the forms are filled. Alternate layers of curd and of mold powder are put into the forms. The mold powder, which will presently be discussed, is sprinkled liberally over the layers of curd by means of a pepperbox. Usually three or four layers of powder should be used in each cheese. The curd is broken up by hand into small pieces, and it is then placed in the forms and gently pressed. The curd is piled above the top of the form. This gradually settles down so that by the time the cheese is ready to salt it is about $4\frac{1}{2}$ inches high. There appears to be no distinct advantage in using a large quantity of mold powder. Experiments have shown that 0.2 of a gram of mold per cheese gives almost as good



FIG. 1.—Filling the forms with curd and inoculating with the mold.

results as 2 grams of the mold. However, four or five liberal sprinklings of the mold are desirable.

Wooden supports, about 2 by 4 inches are placed across the vat about 30 inches apart. A board, covered with a mat, and three forms are placed upon these supports. As the forms are filled, the boards supporting them are transferred to a hand truck which is used to carry the cheese to the drain room.

PREPARATION OF MOLD POWDER FOR INOCULATION.

Mold powder for inoculating purposes is grown in ordinary white bread. Stock cultures of Roquefort mold should be obtained from a reliable laboratory several weeks before the manufacture of the cheese is contemplated. The mold powder is prepared as follows: Either fresh bread, direct from the oven, or older bread, is sterilized

in a dry oven for two hours at 170° C. (338° F.). In either case the bread should be allowed to cool before it is inoculated with the mold. Freshly baked bread is preferable, for it contains more moisture. When the bread is dry-sterilized it may be improved by putting it into a steam sterilizer for a time in order that the bread may regain some of the moisture lost in the dry-sterilizing process. By means of a sterile platinum needle Roquefort-mold spores from an agar culture are transferred to a flask of sterile water. The mixture is then shaken and a portion of it drawn off by means of a sterile pipette. The point of the pipette is thrust into the bread in several places and a small quantity of the liquid allowed to run into the bread in each case. When the pipettes are small several are used for each loaf of bread. It is not advisable to use the pipette twice

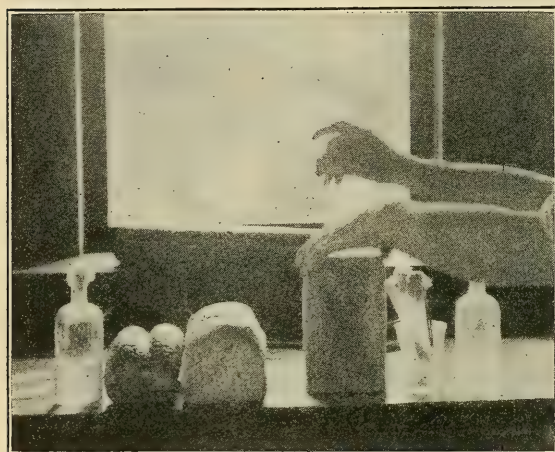


FIG. 2.—Inoculating the bread with pure culture of Roquefort mold.

for inoculating the bread. At least an ounce of the water culture should be used for each loaf; too little moisture will result in a meager growth of mold and a great part of the bread will be wasted. The holes made by the pipette may be covered with a gummed label, and it is advisable to cover the inoculated bread with a thin coating of hot paraffin. The inoculated bread should be put into a moist, cold place (about 50° F.) for several weeks to allow the mold to develop to a stage at which it may be used in the cheese. When grown at a temperature of from 50° to 52° F., it takes two or three weeks for the mold to grow to a stage where it is fit to be made into powder. This condition is indicated by the spreading of the colored mold throughout the bread.

Foreign molds are more likely to cause trouble at a high temperature, and the desired mold appears to make a more vigorous development in the cheese when grown at a low temperature. In some instances in which we have grown the mold at a high temperature (room temperature) and held it for a time before using it, the mold has failed to develop properly, or at least luxuriantly, in the cheese. When there is evidence of foreign mold in the bread either

the infected part should be removed or the entire loaf should be discarded. Although their presence may not be indicated, by spores of another color, under the best conditions there will probably be some foreign molds present. By virtue of the power of Roquefort mold to grow rapidly at a low temperature and in the presence of a high percentage of carbon dioxide in the cheese,⁹ foreign molds appear to cause but little trouble in the cheese. This is especially true when the mold is grown in bread at a temperature of 50° F.

When the mold is thoroughly dry the bread is sliced and ground up by means of a coffee grinder or a mortar and pestle. The mold powder should be kept in a cold, dry place; otherwise there is a tendency for the bread to reabsorb moisture and cause the mold powder to spoil. Usually the bread is ground as fine as pepper. When the bread is cut before drying it is green, and upon drying it assumes a darker hue. The mold will keep for several months in a cold, dry place.

The French process for making the bread for mold development requires 2 parts of wheat flour, 1 part of rye flour, and a great deal of yeast. The bread is acidified by vinegar to prevent the development of foreign bacteria, and then baked. After the mold has grown in the bread at a temperature of 53° F. and at a relative humidity of 88° the bread is dried at 90° F. and made into a fine powder. When growing the mold we have observed no special advantage in using vinegar, especially if the mold is grown at a low temperature, or in making the bread from combined flours.

Another method of mold development suggested by Chavastelon¹⁰ has given good results. The bread is first sterilized, then broken up into pieces about one-half inch in diameter, and soaked in a 3.5 to 3.7 per cent solution of tartaric acid. The pieces of bread rest on a wicker mat which has been sterilized. This arrangement permits a circulation of air. A high humidity and relatively low temperature are maintained and the crumbs of bread are turned once or twice during the period of mold development. By this method the bread becomes more thoroughly molded and there is less unmolded bread than when the mold is introduced into the interior of the loaf. There is a greater chance for surface contamination, however, although there is a smaller loss from unmolded bread.

Handling during draining period.—When loaded with the cheese, the truck is run into the drain room. The temperature of this room should be from 65° to 68° F., and the air moist enough to prevent the cheese from drying out (85° to 90° relative humidity). A continu-

⁹ Thom, C., and Currie, J. N., The dominance of Roquefort mold in cheese, *Journal of Biological Chemistry*, Vol. XV (1913), No. 2, pp. 247-258.

¹⁰ Chavastelon, M. R. Sur la culture pratique de la moisissure verte (*Penicillium glaucum*) pour la fabrication des fromages bleus. In *Compt. Rend. Acad. Agr., France*, 1918, v. 4, no. 18, pp. 364-366.

ous high temperature for draining favors rapid development of the *Oidium lactis* and other destructive microorganisms. Excessive losses as well as an impaired quality of the cheese result from an overdevelopment of these forms of life. An air too dry causes the surface of the cheese to become yellow, hard, and dry. This condition is undesirable because the cheese fails later to absorb the salt properly and great losses are likely to occur in the scraping process. This condition is more likely to arise when there are only a few rather than a large number of cheeses in the drain room. When this room is filled with cheese, continuous ventilation seems desirable in checking



FIG. 3.—Turning the cheese during the draining period.

somewhat the destructive action of *Oidium lactis*. Fifteen or twenty minutes after the forms are filled they should be turned. In turning, one hand raises the cheese from the surface of the mat while the other hand is slipped beneath the cheese and both the form and cheese are quickly reversed. The cheeses should be turned several times during the first day and twice a day thereafter until ready for salting. The object

of the repeated turning is to hasten drainage and to insure an even, smooth surface.

Forms are allowed to remain on the cheese for the first two days and then are removed and washed. The French practice calls for washing both the cheese and forms night and morning, using cold water in summer and warm water in winter. In the work at Grove City the cheese and boards are washed only in the morning. The mats are removed the day after the cheese is made and thereafter the cheese rests directly on the boards. The cheeses are allowed to drain for four or five days, until little whey escapes from day to day. Much of the success in making this cheese depends upon having the cheese dry enough before the salting period.

TABLE 5.—*Water content of cheese one day after making; drained at 68° F.*¹

Sample.	Water.
	<i>Per cent.</i>
No. 1.....	50.78
No. 2.....	51.79
No. 3.....	49.68
Average.....	50.78

¹ The chemical determinations from which Tables 5, 8, and 9 are derived were made by E. H. Parfitt.

A cheese 1 day old should contain about 50 per cent water.

Table 6 shows the daily losses in weight of 67 cheeses held at a temperature of from 70° to 75° F.

TABLE 6.—*Showing daily loss in weight of cheese during the draining period.*

	First day.	Second day.	Third day.	Fourth day.	Fifth day.
	<i>Pounds.</i>	<i>Pounds.</i>	<i>Pounds.</i>	<i>Pounds.</i>	<i>Pounds.</i>
Total weight.....	549.70	506.5	370.93	363.9	357.93
Average weight per cheese.....	8.05	7.59	5.53	5.41	5.34

Table 7 shows the daily loss through drainage and indicates that there is not a great loss in weight after the first few days in the draining process.

TABLE 7.—*Loss in weight of two lots of cheese during the draining period.*

	First day, temperature 74.3° F.	Second day, temperature 68° F.	Third day, temperature 68° F.	Fourth day, temperature 64.4° F.	Fifth day, temperature 69.8° F.	Sixth day, temperature 68° F.
	<i>Pounds.</i>	<i>Pounds.</i>	<i>Pounds.</i>	<i>Pounds.</i>	<i>Pounds.</i>	<i>Pounds.</i>
Total weight.....	96.97	63.53	60.68	58.54	57.11	56.22
Average weight per cheese.....	8.81	5.77	5.51	5.32	5.19	5.11

TABLE 8.—*Water content of cheese at time of salting.*

Sample No.	Water content.
	<i>Per cent.</i>
1.....	45.50
2.....	45.08
3.....	45.20
4.....	45.70
5.....	44.60
Average.....	45.21

Water determinations were made on the samples above after they had drained and were ready for the salting process. These samples were taken from the cheeses recorded in Table 6, which were

held under a uniform temperature in the draining process. At the time of salting a cheese should contain about 45 per cent water.

Salting.—Roquefort cheese is salted on the outside at a temperature of approximately 48° F. and in a dry room. It should be salted the fourth or fifth day after making. During this period it is desirable to have some ventilation to remove the excess moisture occasioned by the salting. The entire salting process should require about 10 days. At the time of salting the cheese should be moist but not wet nor yellow. Having the cheese too dry may result in undersalting. The cheeses are carried on a hand truck to the salting room and eight cheeses are piled on each board. In order that

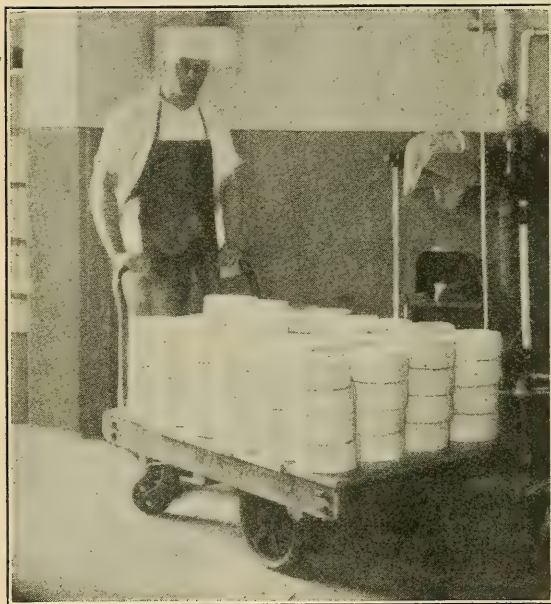


FIG. 4.—Transferring the cheese from the draining room to the curing room.

the cheeses may acquire the same temperature as the salting room they should be left there overnight.

Fine, dry salt then is rubbed vigorously over the surface of the cheese, and all the salt that will adhere to the cheese is used. The salt permeates the cheese and tends to remove the excess whey. After the cheeses are salted they are put in piles of two or three, and the following day their position is reversed, with no addition of salt. On the

third or fourth day they are again salted in the manner previously described.

After an intervening day the cheese is sprinkled over very lightly. Some experience is required before a person can salt Roquefort cheese successfully, and this work must be very carefully done. Some system of piling or marking should be used in order that one may tell at a glance the stage of salting. Unless great care is taken there is always a tendency either to undersalt or to oversalt. Undersalting is the greater evil. As previously noted in the analyses of Roquefort cheese each cheese should contain approximately 4 per cent salt and 40 per cent moisture. Since salt amounting to about 10 per cent of the weight of the cheese is used, there is a loss in drain-

age of about 6 per cent. This high salting, as compared with the salt used for other cheese, is sufficient to prevent an excessive development of *Oidium lactis*. The practical elimination of this organism is essential.

While a higher temperature and a shorter draining period have sometimes been used in salting the cheese,¹ it is believed that by using a temperature of 48° to 50° F., similar to that in the French practice, it is possible to salt the cheese more uniformly and with less danger of oversalting. Some manufacturers are now salting the cheese a day or so after making; but although this method has been successful in some cases, there is danger of oversalting.

Salting by immersing the cheese in brine has not been successful, for when this method is used a rind forms and the cheese often cracks, as a result of the intense contraction of the surface in the expelling of whey. The object of a low temperature for salting is to reduce losses and favor the development of the desirable forms of mold.



FIG. 5.—Salting the cheese. Fine, dry salt is rubbed vigorously over the surface of the cheese, and all the salt that will adhere is used.

TABLE 9.—Water and salt content of cheese after salting.¹

Sample No.	Water.	Salt.
	<i>Per cent.</i>	<i>Per cent.</i>
1.....	42.45	4.61
2.....	41.65	4.70
3.....	41.60	4.72
4.....	42.45	4.48
5.....	41.95	4.53
6.....	41.40	5.28
Average.....	41.91	4.72

¹ The temperature at time of salting was from 46.6° to 48.2° F.

The salt in the samples (Table 9) is a trifle high. As it requires about three weeks before the salt reaches an equilibrium in all parts

¹¹ Bulletin No. 79, Storrs Experiment Station, Storrs, Conn. Studies relating to the Roquefort and Camembert types of cheese, Charles Thom, J. N. Currie, and K. J. Matheson.

of the cheese, it is likely that the salt percentage would be slightly lowered by subsequent scrapings. Some of the water, possibly 1 or 2 per cent, will be lost in ripening before the cheese is enveloped in foil.

First scraping.—After a week or so in the draining room the cheeses are given their first scraping. This is done with knife or an ordinary wall scraper. At this time the slime, which is composed of the softened cheese, whey, salt, and the microorganisms, is carefully removed. Care should be taken not to scrape the cheese too deep, for the surface at this period contains a high percentage of salt.

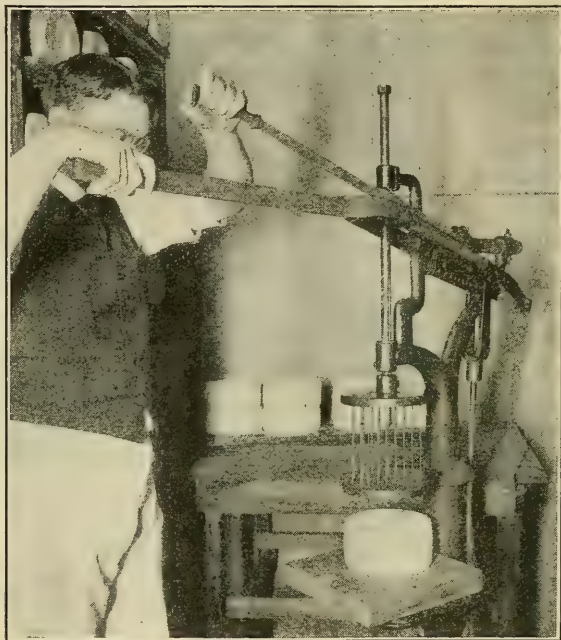


FIG. 6.—Each cheese is punched, or pierced with steel needles, to admit oxygen and aid the development of the mold.

In all this work at Grove City there was a loss of about $3\frac{1}{2}$ per cent of cheese. Figuring on the basis of $4\frac{3}{4}$ pounds for the weight of each cheese, an examination of 1,040 cheeses showed a loss of 3.28 per cent. The losses in French cheese are somewhat higher.

Punching.—Punching follows the first scraping of the cheese, which takes place in from 10 days to 2 weeks from the time the cheese enters the curing room. Oxygen is necessary for the proper development of the mold, and in order to insure its entrance each cheese is pierced with a steel needle in from 20 to 60 places. An examination of three imported cheeses shows that they average 20 holes per cheese; domestic cheese made at Grove City is punched about 30

times. The needles are about 3 millimeters, or $\frac{1}{8}$ -inch in diameter. In France a specially constructed machine is used for this purpose and the cheeses may be punched at the rate of from 6 to 12 a minute. By the use of a remodeled drill press provided with steel needles, as shown in figure 6, one man can punch 50 or 60 cheeses an hour. Punching favors the mycelial growth and hastens the ripening. After being punched the cheeses are set on edge instead of on their flat surfaces, as has been the case heretofore. Placing the cheese in this position insures a maximum quantity of air in contact with the mold.

RIPENING THE CHEESE.

The temperature of the caves of Roquefort varies from 4° to 8° C. (39.2° to 46.4° F.). According to Marre, "the best caves are those where the temperature does not exceed 5° C. (41° F.) when the caves are empty, and 7° to 8° C. (44.6° to 46.6° F.) when the caves are filled with cheese. Unfortunately there are many caves in which the temperature is higher and reaches 10° to 12° C. (50° to 53.6° F.)."¹² The air of the rooms is cooled by evaporation caused by the air rushing through the channels with great intensity. In the winter the air change is not so rapid as in the summer; nevertheless the temperature in the caves remains practically the same the year round. According to their situation, number, and quality, the air channels in these caves have a greater or lesser value. Often these currents of air have a velocity of 5 meters a second. According to Saussure's hygrometer these rooms have a relative humidity of from 90° to 100°.¹³

The conditions which appear to be most ideal for curing cows'-milk Roquefort, in the experience at Grove City, are summarized as follows:

TABLE 10.—*Conditions favorable for curing Roquefort cheese.*

Period.	Temperature.	Relative humidity	Ventilation.
	<i>Degrees F.</i>	<i>Degrees.</i>	
First week.....	65-68	¹ 85-90	Slight.
Second week.....	48-50	80-90	Considerable.
Third and fourth weeks.....	48-50	¹ 80-90	Do.
Second and third months.....	46-48	90-95	Moderate.
Fourth and fifth months.....	46-48	¹ 80-90	Considerable.

¹ About.

The humidity and ventilation indicated here can not be expressed with any greater degree of exactness at the present time. They serve to show in a general way, however, the conditions that have proved most successful.

¹² Marre, E., *Le Roquefort*, p. 132.

¹³ Marre, E., *Le Roquefort*, p. 134.

EQUIPMENT FOR CURING ROQUEFORT.

It has been found necessary to have well-insulated curing rooms and a special kind of conditioning apparatus to approximate the conditions in the cases of Roquefort. In the plant at Grove City, Pa., the sides, tops, and bottoms of the curing rooms have been insu-

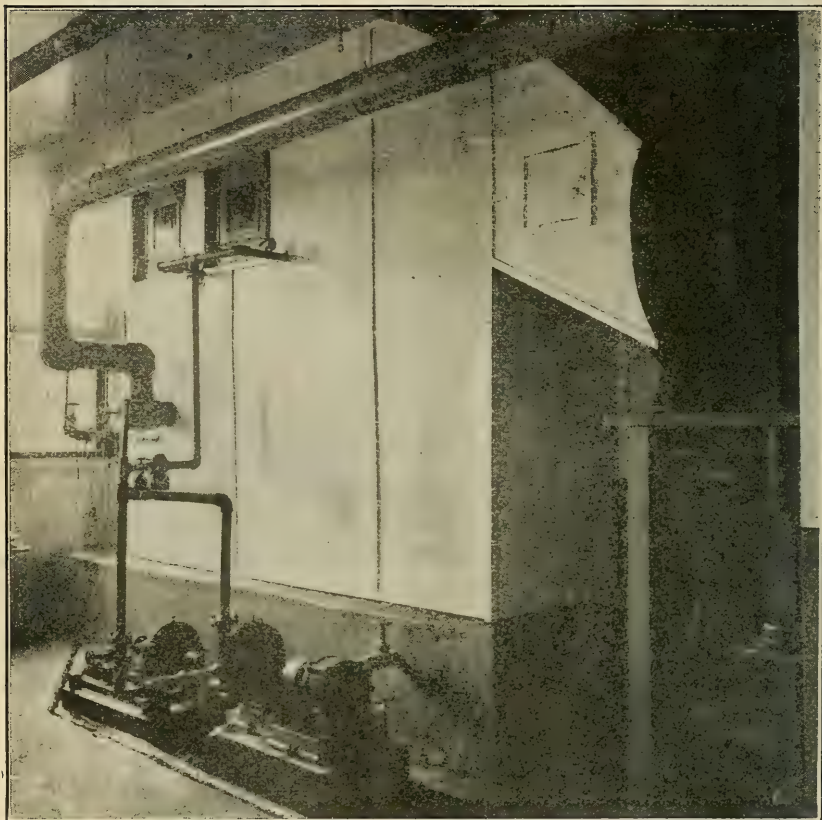


FIG. 7.—Refrigerating and conditioning apparatus used for maintaining the proper temperature and moisture conditions in curing and storing Roquefort.

lated with 4 inches of cork laid in hot asphalt and covered with Portland-cement plaster.

Conditioning equipment.—Several years of experience in the manufacture of mold-ripened cheese has proved the inefficiency of the ordinary means of controlling the humidity. No great difficulty has been experienced in adjusting the temperature to the desired point by the use of proper refrigeration. Attempts to hold the temperature as low as is necessary with Roquefort and still maintain a high humidity meet with more difficulty. Cooling Roquefort curing rooms by means of direct-expansion or brine coils has not proved successful. With such a system moisture is continually removed

from the cheese, and as a consequence it becomes too dry. Cheese handled in this manner ripens slowly, surface molds fail to develop, and the flavor is impaired. If much humidity is used the refrigerating coils become coated with ice and frost and the efficiency of the refrigerating system is greatly reduced.

Air conditioning.—Air conditioning has been used in other industries to regulate artificially the atmospheric conditions of a room or building and maintain and regulate certain desirable and definite conditions of humidity, temperature, and air purity. So far as is shown by the literature, no one has adopted this method of conditioning the air for curing cheese. It is not only desirable to regulate cheese-curing conditions, but to prevent the mold from one curing room from mixing with the air of another and thereby causing trouble. There is little danger of such condition causing trouble with Roquefort. It is quite possible, however, that the air from a Roquefort room may contaminate the air in a Camembert room.

The system for regulating the temperature and humidity used in the curing rooms at Grove City includes an air washer with a fan for circulating the cooled air in a closed circuit throughout the rooms. The air washer consists of a series of sprays through which the air is drawn on its return from the rooms. The washer is so arranged that the water for the sprays flows over direct-expansion ammonia coils, which cool it to about 32° F. Below the coils is a storage tank from which the water is forced through the

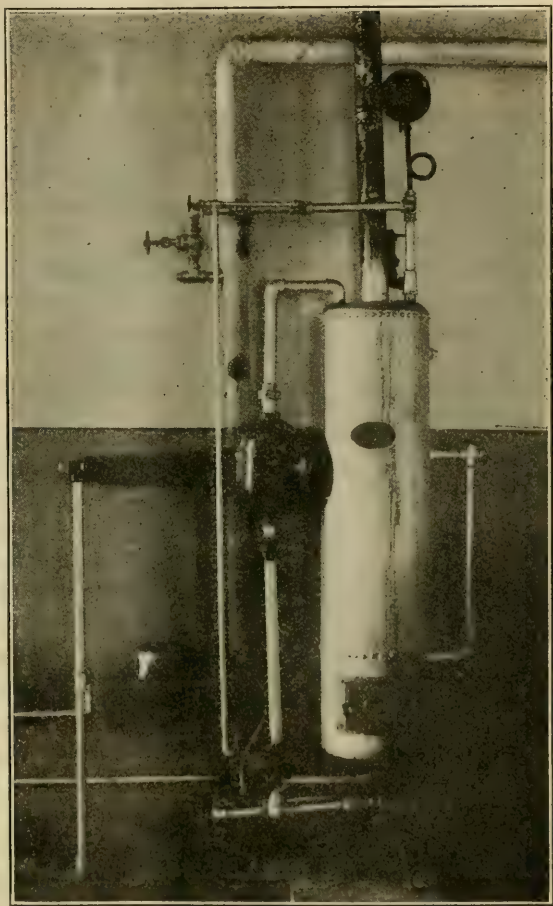


FIG. 8.—Apparatus for maintaining a constant humidity.

sprays by a rotary pump. Between the sprays and the fan is a series of baffle plates to remove the entrained water. Insulated ducts carry the air into the curing rooms through the ceilings. Two inlets are provided for a room 11 by 19 feet. The temperature of the room is held constant by dampers in the inlets, operated by compressed-air motors. These motors are regulated by a thermostat. Four outlets in the ceiling of each room connect with a common duct, which returns the air to the washer. This system insures a thorough circulation of air within the room. By this arrangement the air leaves the air washer at a temperature of 40° to 45° F. and in a saturated condition. As it mixes with the warmer air of the curing room the relative humidity drops, and it is necessary in some cases to bring it to the desired point by introducing additional moisture. This is done very satisfactorily by blowing a jet of steam into the current of air as it comes into the room. This steam is carried under very low pressure and may be regulated by hand so that the relative humidity is held within narrow limits. The steam is at once absorbed by the air, and while it adds a small amount of heat it has given very satisfactory results.

PHENOMENA OF RIPENING.

During the first weeks there is a gradual development of a reddish slime upon the surface of the cheese, interspersed with patches of white and green mold. The latter in most cases is the Roquefort mold. Judging from descriptions, domestic Roquefort does not take on the same vigorous development of the white mold as occurs with the French cheese. Sometimes the slime fails to develop rapidly. By using some of the scrapings from imported cheese and sprinkling the domestic cheese with a mixture of these scrapings and water the development of this mold growth may be brought about without great difficulty.

After the first scraping there is only a slight development of the white and green mold, but there is a much greater development of the slime organism. The growth needs to be removed every few weeks in order to permit the air to reach the mold in the interior of the cheese. The development of the mold and slime is sufficient to destroy the acidity of the cheese, and the removal of this growth is necessary to prevent a putrefactive fermentation. Like the mold on the outside, the mold on the inside does not appear to develop to any marked extent after the first scraping. When held before an electric light, if the cheese is cured at a temperature of from 48° to 50° F., the hyphæ of the mold may usually be seen through the punch holes in less than 10 days after punching.

Within two or three weeks the colored mold is often well developed, and within a month there is very likely to be as much colored

mold visible as when the cheese is cut, several months later. The mold in the center of the cheese appears to develop more rapidly than that nearer the surface, possibly because of a less high concentration of salt. In the earlier stages of ripening, the flavor of the cheese often appears bitter to the taste. Later this condition disappears and a sweet, piquant flavor is noticeable, with little or no suggestion of bitterness.

Under the proper conditions the texture of the cheese can be made to approximate closely that of an imported cheese. The typical peppery flavor is found in some cheese, while in other cheese it is quite lacking. Sometimes there is an over-development of sharpness in the flavor and the cheese becomes repellent to the taste. This is said to be due to an intense oxidation, as is evidenced by the formation of formic acid.¹⁴ When the cheese is held at too high a temperature for a long period this condition may result in a cheese that is too piquant.

At the time of ripening, Roquefort cheese should contain from 40 to 42 per cent water. This should

be reduced to from 38 to 40 per cent by the time the cheese is put into the foil. A high humidity prevents the cheese from drying out. Dryness causes a cheese to ripen slowly; the texture becomes too waxy and the typical flavor is lacking. Moist conditions increase the rapidity of growth of the bacteria and mold on the surface. Despite much investigation, there are no experimental data to show that the surface growth aids in ripening the cheese, yet its presence is always associated with the best grades of cheese. The function of the slime appears to be to check the surface mold and aid in keeping the cheese in a sweet and normal condition.



FIG. 9.—Scraping the cheese allows the air to reach the inside and permits the proper development of the mold.

¹⁴ Lebrou, P., Les applications du froid en Aveyron à la préparation des fromages de Roquefort. In 2d Intern. Cong. Refrigeration Industries, Vienna, 1910, p. 428.

Occasionally the mold and flavor fail to develop, in which case the cheeses are repierced and again exposed to the free air of the curing rooms. At the time of enveloping in foil there should be an abundance of mold and some flavor; however, the flavor appears flatter and less pronounced than after the cheese has been left in the foil for a few months. Whenever cheeses are repierced care must be taken to maintain a high humidity and low temperature, or they will become dry, friable, the mold will take on a dark color, the flavor will be sharp and unpleasant, and the cheeses will be of poorer quality than before this operation. The cheeses should be wrapped in tin foil within two or three weeks after the second piercing.

In the preliminary work by the Bureau of Animal Industry it was often necessary to use a temperature of from 50° to 60° F. and under these conditions a great deal of difficulty was caused by the invasion of the surface slime into the punch holes. A high humidity and temperature result often in the invasion of the slime into the interior of the cheese, which not only causes a very unattractive appearance but impairs the flavor of the cheese. This serious difficulty has been partially, if not wholly, eliminated by the use of low temperatures, from 45° to 50° F. This is one reason why a low temperature for curing this cheese is desirable.

Ripening period.—Roquefort cheese from cows' milk requires from three to five months to ripen. The ripening period may be shortened by raising the moisture content of the cheese, but this will be at the expense of quality. By the use of refrigeration the cheese may be made when milk is abundant, and ripened and marketed in the winter, when it commands a higher price; in fact it may be made the year round. The imported cheeses are ripened in from one to three months and often they are sold directly from the curing shelves without preliminary ripening in the foil. With cows'-milk Roquefort it is often difficult to ripen the cheeses under three months, and a longer time is better. The best results have been obtained by ripening three months on the shelves and at least two months in the foil. It has so far not been possible to obtain cheese with the best flavor unless ripened in foil. When the foil-wrapped cheese has been ripened to the desired point, it will keep in good condition for from eight months to a year, provided it is held at a low temperature and is not too moist. Preferably the cheese should be held at a temperature of only a few degrees above 0° C. or 32° F. However, rather moist cheese has been kept from six to eight months in good condition at a temperature from 45° to 50° F. During this period the cheese did not deteriorate but rather tended to improve in quality and become sweeter and more fragrant. Cheese that is very moist may be ripened in a shorter period but it is not so easily

handled, losses are higher, and it is far more easily damaged in transit.

LOSSES IN CURING.

The losses of cheese by scraping, brushing, and handling are quite heavy. With Roquefort, special brushing equipment reduces both the losses and the cost of manufacture. According to reports on the industry in France a brushing machine can brush from 4,500 to 5,000 cheeses in an 8-hour day, and requires only two or three workers. With a knife a worker is able to scrape from 200 to 300 cheeses a day. It has been found in French practice that at each scraping, losses are reduced from 5 per cent where a knife is used to one-half of 1 per cent by the use of the brushing machine. Without special precautions with respect to refrigeration, depending on the perfection of ripening, salt content, and quality of the cheese, the losses run from 16 to 22 per cent. In France the first scraping is done by machinery. Scrapings at the ripening stage are made by hand. Normally the cheeses are exposed to the air in the caves from one to four months, and it is necessary to brush them every 10 or 15 days. In order to have a supply of cheese the year round, the imported cheese, which is manufactured only six or seven months in the year, is subjected to low temperatures of refrigeration and may be withdrawn according to the demands of the market. By this system the cheese is wrapped in foil and then subjected to a very low temperature. Later it is exposed to the air of the caves and ripened at a higher temperature. Often the cheese is held a year at a temperature just a little above 0° C. (32° F.). At this temperature practically all fermentations are checked. When again subjected to the air of the caves the cheese ripens with redoubled intensity and is more quickly broken down than when the other system is used and the cheese is not ripened in the foil. By the use of the holding system more delicate flavors are developed than when the cheese is ripened and shipped directly from the curing rooms. The practice just described reduced losses from 21 per cent to 9 per cent. These figures, which were given by Marre, are based on a comparison of approximately 869,000 pounds of cheese ripened without refrigeration and 1,001,000 pounds ripened with refrigeration.¹⁵

The domestic cheese is first ripened to a certain degree and put into the foil. The cheeses are scraped three times. There is a loss of 3.28 per cent in the first scraping, 2.12 per cent in the second, and 2.02 per cent in the third, making a total loss of 7.42 per cent. These figures were based on an arbitrary figure of 4½ pounds as the average weight of each cheese. More than 1,000 cheeses were used in obtain-

¹⁵ E. Marre, *Le Roquefort*, pp. 142-146.

ing the figures for each scraping. The loss in cows'-milk Roquefort seems to be somewhat less than that of sheep's-milk Roquefort. This may be due to a difference in the nature of the two milks or to a more vigorous development of the slime organism in the case of sheep's-milk cheese. At any rate the rather heavy losses that occur in the domestic and foreign cheeses indicate that these losses are normal and that probably this fermentation is rather to be encouraged than discouraged even though the losses may seem somewhat heavy.

USE OF TIN FOIL.

The function of the tin foil is to prevent desiccation, excessive oxidation, and the escape of the volatile substance from the cheese. After the last scraping the cheeses are wrapped in tin foil. There always seems to be an improvement in the quality of the cheeses wrapped in foil as compared with those not handled in this manner. Curing the cheese in the foil for a time appears to aid in the development of the sweet flavor and reduces to a minimum the strong, biting, and soapy flavors which may occur when the cheese is exposed too long to the action of the air. Because of the ripening changes going on within the cheese it has a slightly higher temperature than the surrounding air. The tendency of the moisture of the cheese to condense when covered with the foil and held at a low temperature must cause a circulation of the ripening agents. Here the foil acts as a condensing medium, prevents the escape of liquid and volatile substances, and the surface of the cheese tends to have the same homogeneous texture and composition.

The use of paraffin as a substitute for tin foil has not proved to be satisfactory. Unless the surface of the cheese is very dry the paraffin does not adhere readily in a coating of less than about $\frac{1}{8}$ inch. A normal cheese is entirely too soft for a thin layer of paraffin, such as might be used with Cheddar cheese. Because of the soft nature of the cheese and because the surface of the coating may readily be broken the paraffined cheese is sure to suffer from lack of protection from the dry air. When foil is used the cheese is better protected and may be wrapped more easily and securely with parchment paper.

While tin foil as a covering is more expensive than paraffin, it is more efficient and more attractive in appearance, so that the additional expense seems justifiable when the value of the product is considered.

Shrinkage.—The loss from shrinkage will vary, depending upon the moisture content of the cheese when enveloped in foil and the temperature and length of time held before shipment. With 16 cases of cheese held for a period of five months, at a temperature of from 45° to 50° F., there was an average loss in weight of 4.58 per cent. These cheeses were a little too moist when wrapped in foil.

Even under the best of conditions, however, there is some shrinkage, due largely to evaporation.

Yield.—Milk testing 4 per cent butterfat should yield from 10 to 11 pounds of cheese per 100 pounds of milk. These figures are based on the final weight of the cheese after curing and when ready to be shipped.

COST OF MANUFACTURE.

The figures given on cost of manufacture are based upon milk testing 3.8 per cent fat and costing \$3.20 per 100 pounds. The daily costs of fuel, water, electricity, and depreciation are based on figures supplied by the engineer of the Dairy Division. The yield of the cheese was figured at $10\frac{1}{2}$ pounds for each 100 pounds of 4 per cent milk. An average weight of $4\frac{3}{4}$ pounds per cheese was used in these figures. The labor was figured as one man to each 1,000 pounds of milk and the cost of labor at \$75 a month. This did not include supervision of work; the figures were based on the use of one-third of the curing space in the factory and on one-third of the other operating expenses. It is estimated that 5,000 pounds of milk were made into cheese daily, based on 26 working days in each month. The foil was charged at \$1.10 a pound and the shipping boxes at \$0.52 each. Salt was charged at $\frac{1}{4}$ cent a pound. The following is the estimated cost of producing Roquefort cheese.

TABLE 11.—*Estimated cost of producing cows'-milk Roquefort cheese.*

Item.	Cost per pound.
Interest, repairs, and depreciation of insulation.....	\$0.0047
Interest, repairs, and depreciation of refrigerating equipment.....	.0047
Cost of fuel.....	.0131
Cost of electricity.....	.0205
Interest, repairs, and depreciation of cheese equipment.....	.0058
Interest on money invested in building, insurance, taxes, repairs, and depreciation.....	.0443
Cost of water and steam.....	.0010
Cost of milk.....	.3047
Cost of labor in making cheese.....	.0220
Cost of labor in refrigeration.....	.0104
Interest on cheese and labor.....	.0085
Cost of foil.....	.0105
Cost of boxes.....	.0091
Cost of salt.....	.0002
Cost of rennet.....	.0001
Cost of wrapping paper and string.....	.0036
Total cost per pound.....	\$0.4632

MARKETING METHODS.

Roquefort cheese is marketed in wooden boxes holding from 6 to 12 cheeses each. The inside dimensions of the 12-cheese boxes are 8 by 8 inches by $3\frac{3}{4}$ feet. The box is divided with boards into three compartments, and the material used is $\frac{3}{8}$ -inch pine, with $\frac{1}{8}$ -inch ends and dividing boards. The latter protect the cheese and give strength to the box. The foil should be wrapped neatly and securely

about the cheese. The dimensions of the foil are 22 by 13 inches, and it has a weight of 1 pound for 6,500 square inches. The foil is separated from the cheese by means of parchment paper to which it is attached. Ordinarily the trade name and design are printed in black upon the foil. When ready to ship, all cheeses are wrapped in strong, brown, wrapping paper, tied with a cord, and for convenience the net weight of the cheese is marked on the paper. Both paper and foil tend to hold the cheese in shape and protect it in transit. The wrapped cheese is then packed in sawdust, pine shavings, or excelsior, in

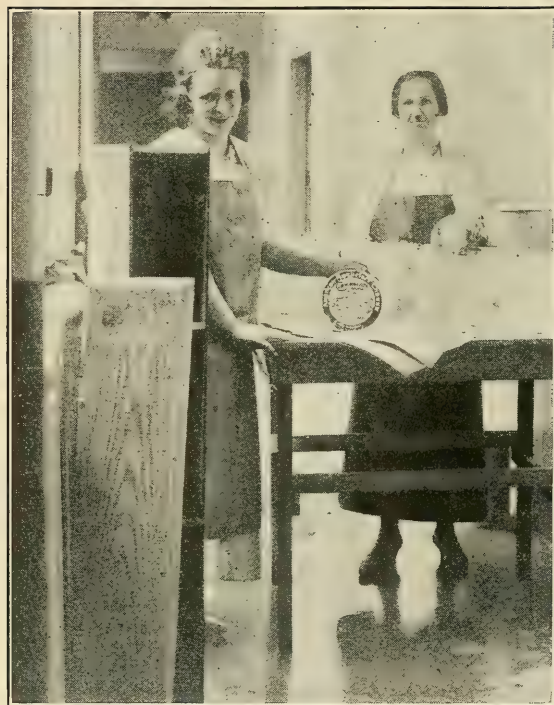


FIG. 10.—Packing Roquefort for shipment. The cheeses, wrapped in tin foil and wrapping paper and surrounded with sawdust, are packed 12 in a box.

order to absorb any leakage brought about by a change from low to high temperatures. No difficulty has been experienced from the cheese absorbing woody odors from the box or packing material.

The wholesale price received for the cheese has averaged 10 or 15 cents below that of the imported cheese. A natural prejudice, which is hard to overcome, exists against domestic cheese made from cows' milk. The cheese has been criticised most often for its yellow color and the lack of the char-

acteristic piquancy of the imported cheese. It is probably impossible to produce on an average a cheese from cows' milk as white as that from sheep's milk. Some of the cheese made, however, has been above reproach in respect to both color and piquancy.

POSSIBILITIES FOR DOMESTIC ROQUEFORT.

The making of cows'-milk Roquefort on a commercial scale should not be attempted by inexperienced operators or where the equipment for proper curing conditions is lacking. In the past, efforts to make Roquefort on a factory scale have failed, largely because of the fact that these factors have not received proper consideration.

Undoubtedly a market can be developed for a cows'-milk Roquefort, but it will require advertising and a proper selling organization to break down the existing natural prejudice against a domestic cheese of this character. While the cheese, in most cases, can be distinguished from sheep's-milk cheese, it will require a connoisseur to make this distinction always, so closely does this cheese resemble the imported article in respect to flavor, texture, and color of mold. With only a limited commercial experience at present there is reason to believe that future work will tend to improve both the quality and the uniformity of the product and that eventually cows'-milk



FIG. 11.—Mold growth in cows'-milk Roquefort cheese made at Grove City, Pa.

Roquefort will become one of the established varieties of cheese made in the United States.

SUMMARY.

The Roquefort cheese from France is made of sheep's milk and is one of the oldest cheeses of which there is record. The average composition of good Roquefort cheese is about as follows:

	Per cent.
Water.....	38
Fat.....	32
Protein.....	20
Ash.....	6
Salt (NaCl).....	4

Sheep's and cows' milks differ physically and chemically. The ratio of the fat to the protein is about the same in either case.

Fresh, clean milk is essential. Three or four per cent of a starter is used and the milk brought to an acidity of 20 to 23 before setting.

The milk is warmed to from 83° to 85° F. and set with rennet at the rate of 3 to 4 ounces per 1,000 pounds of milk.

The milk is allowed to set for from 1 to 1½ hours and the curd is then cut into small pieces with a $\frac{5}{8}$ -inch curd knife.

Ten minutes after cutting, the curd is scooped on to a draining rack and allowed to drain for about 20 minutes.

As the curd is placed in the forms it is sprinkled three or four times with the mold powder.

The cheese is turned three or four times the first day and at least twice a day thereafter until salted. The temperature of the drain room should be from 65° to 68° F., with a relative humidity of 85° to 90°.

The cheeses in the drain room are washed every day for four or five days, after which they are salted in a special room in which a temperature of 48° F. and a relative humidity of between 80° and 90° are maintained. The salting process requires a week or 10 days. A special conditioning apparatus is necessary to maintain the proper temperature, humidity, and ventilation. The cheeses are then pierced 30 or 40 times and placed on the shelves, where they rest on their edges instead of their flat sides as previously.

By means of refrigeration and a special conditioning apparatus the cheeses are ripened at a temperature of from 45° to 50° F. with very little ventilation. During the salting period and while the cheeses are wrapped in foil the air should be cold and dry.

The cheeses are ripened for two or three months; during this period they are scraped every three or four weeks, with an aggregate loss of from 7 to 8 per cent. After ripening, the cheeses are enveloped in foil and held for at least one or two additional months.

At Grove City, Pa., the estimated cost of making 1 pound of cows'-milk Roquefort was \$0.46.

With 4 per cent milk the yield of cheese should be 10 or 11 pounds per 100 pounds of milk.

When cured the cheeses are wrapped in parchment-lined tin foil packed in excelsior, and shipped 12 in a box.

With proper curing conditions and experienced help cows'-milk Roquefort may be manufactured successfully.



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WM. A. TAYLOR, Chief



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INHERITANCE OF RAMOSE INFLORESCENCE IN
MAIZE.

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THE RAMOSE EAR VARIATION IN MAIZE.

From the standpoint of the origin of the ear of maize, perhaps the most instructive variation is the ramosé type of inflorescence discovered by Gernert (4)¹ in a strain of Leaming Yellow Dent. In this variation the simple pistillate inflorescence is replaced by a compound structure which resembles somewhat the staminate inflorescence. Practically all the grain is borne on branches, the central axis bearing seeds at the extreme apex only. (Pl. I; see also Pl. X.) The larger surface on which seeds may be borne increases the potential production, although the actual yield of grain is much less than on normal plants of the parental variety. A single ramosé ear has been found to produce 4,700 pistils (Pl. II), while the production of one-quarter of that number would be unusual on an ear of the parental Leaming variety. The failure to produce grain in quantity commensurate with the number of pistils seems to be due, at least in part, to the mechanical difficulty of exerting such a large number of pistils through the ends of the husks, although there doubtless are other restricting factors.

¹ Serial numbers in parentheses refer to "Literature cited" at the end of this bulletin.

While the pistillate inflorescence is entirely branched, none of the other characteristics of a normal ear are altered. The glumes are membranaceous and inconspicuous, the spikelets are paired and practically sessile, one flower only is developed in each spikelet, and there is no indication of the development of stamens. The branches bear four rows of spikelets, being similar in this respect to the branches of a tassel. The ramose ear, therefore, may be considered as a reversion to a more primitive type in only the one character of branching.

Accompanying the ramose pistillate inflorescence is an almost equally striking alteration in the form of the staminate inflorescence. (See Pl. XIII.) In normal maize the tassel has a few branches at the base and terminates in a single upright spike bearing four or more rows of paired spikelets. This terminal spike usually exceeds half the length of the entire inflorescence, and in some varieties its relative length is much greater. The transition from branches to a single central spike is abrupt, the upper and lower branches being of nearly the same length. In the ramose type of tassel the branching is continuous, extending from the base to within a few centimeters of the apex, leaving a very short central spike, while the total number of branches in extreme cases exceeds 400. These branches decrease gradually in length until they consist of but three or four spikelets on rather elongated pedicels, with an almost imperceptible transition from branches to pairs of spikelets.

As with the ramose ear, the tassels with their large number of branches produce a far larger number of spikelets than the tassels of commercial varieties, and also a greater amount of pollen. The whole tassel has a distinct conical shape quite unlike that of the normal form.

Since the ear of the *Ramosa* variety is branched in a manner similar to the tassel, with an absence of a predominating central spike, it would seem reasonable to conclude that the differentiation of the sexes in maize occurred before the loss of the lateral branches, and the central spike of the tassel may be assumed to have developed simultaneously with the single-spiked ear.

While the ramose type of inflorescence has been found to segregate as a unit in crosses with the normal form (1), no evidence has been presented to show whether this seemingly simple Mendelian character has suffered any alteration as a result of such hybridization and, further, whether the normal plants segregating from ramose hybrids have undergone changes in the structure of the inflorescence.

The opportunity to measure the effect of hybridization on Mendelian characters is unique in *Ramosa* $\times$ normal crosses. The ramose variation is large, affecting both staminate and pistillate inflores-

cences, and is readily classified qualitatively, while the component parts are numerous and subject to definite quantitative study.

DESCRIPTION OF THE PARENTS.

In the selection of a variety to cross with *Ramosa*, fortunately one was found which, in tassel dimensions, varies from the normal almost as much as the *Ramosa*, but in the opposite direction. The staminate inflorescence of this variety is of the familiar form, but it is extreme in having relatively few branches and a central spike which in some cases is half a meter in length (Pl. III). The pistillate inflorescence is normal, consisting of a single spike with 12 to 16 rows of seeds. This variety was collected by Dr. Palmer at Chihuahua, Mexico, and its native name *Gordo* has been retained.

Three crosses were made between the two types, *Ramosa* plants being used as female parents. These hybrids were designated Mh157, Mh158, and Mh159. A few first-generation plants were grown and self-pollinated, furnishing seed for the second generation. First-generation plants were grown again in larger numbers when the second-generation progenies were planted.

Fourteen characters were recorded for the second generation. These characters fall into two groups, those relating to the terminal staminate inflorescence and those relating to the pistillate inflorescence.

TASSEL GROUP.

Type of tassel: The tassels were classified into *ramose* or *normal* from their general appearance.

Length of the branching space: The length of the rachis in centimeters from the lowest tassel branch to the uppermost.

Length of the central spike: The length in centimeters of the single spike from the uppermost tassel branch to the tip of the spike. The combination of this measurement with that of the branching space gives the total length of the tassel.

Length of the uppermost tassel branch: The length in centimeters of the uppermost branch of the tassel. In *ramose* inflorescences it often is difficult to determine where the branches end and the pediceled spikelets begin.

Length of the lowest tassel branch: The length in centimeters of the lowest primary branch of the tassel.

Total number of branches: This measurement includes all primary and secondary branches as well as branches of a higher order.

Central spike index: The length of the central spike as a percentage of the total tassel length.

EAR GROUP.

Type of ear: Classified into *ramose* and *normal* from general appearance.

Number of branches: The number of branches on the ear. In typical *ramose* ears it is difficult to determine the total number of branches, since those at the apex are much subject to environmental influence. It has been the practice to record any ear with more than 50 branches as *ramose*.

Number of rows of spikelets on the terminal spike of the ear: This character corresponds to the number of rows on a normal ear, but on many ramose ears the terminal spike is so short and irregular that the number of rows can not be definitely determined.

Length of the terminal spike: The length in centimeters of the unbranched portion of the ear. This measurement corresponds to the length of the central spike of the tassel.

Terminal spike index: The length of the terminal spike as a percentage of the total length of the pistillate inflorescence.

Length of the entire ear: The length of the pistillate inflorescence in centimeters, including the branched and unbranched sections.

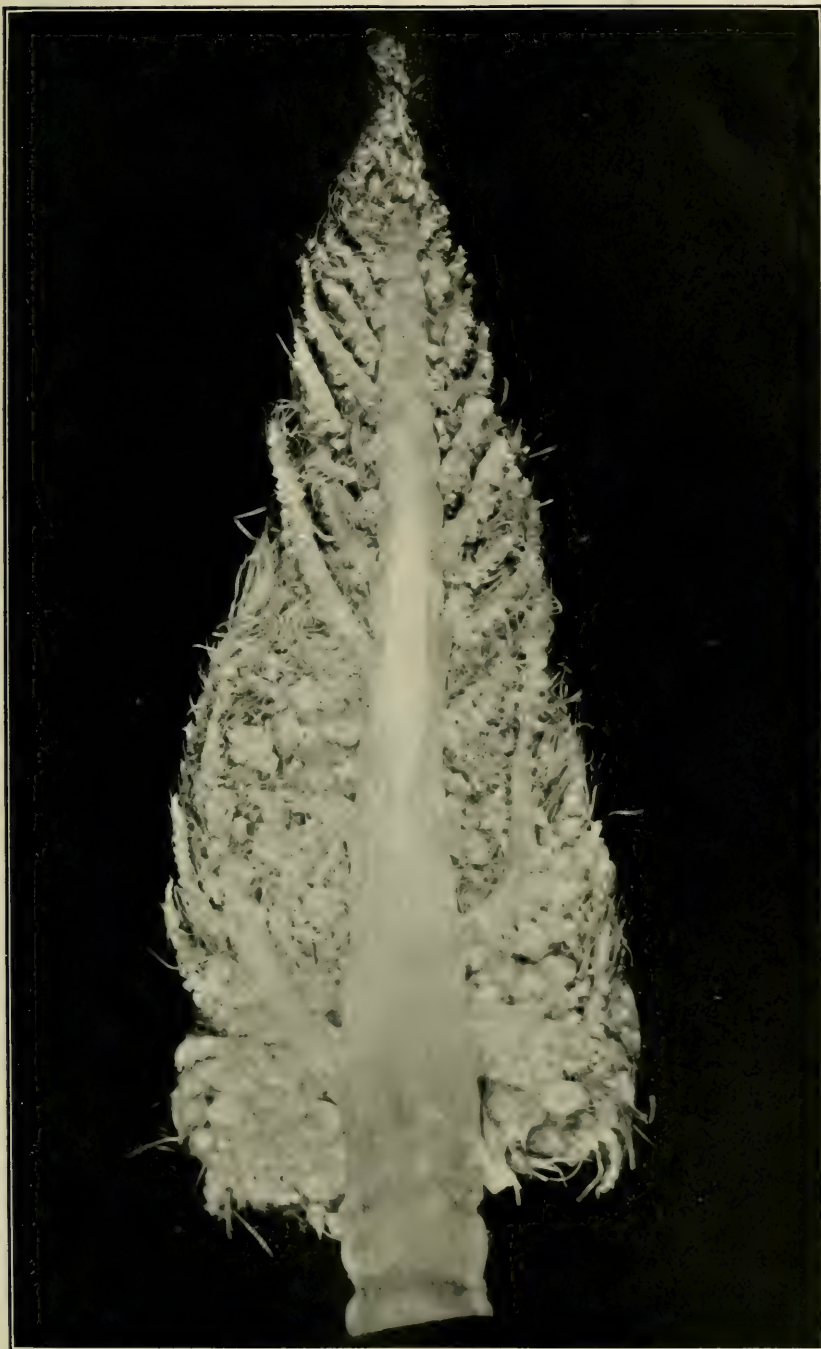
FIRST GENERATION.

The ramose characteristics of both pistillate and staminate inflorescences entirely disappeared in the first generation. This was in accordance with the results of other investigators as well as the previous experience of the writer.

Measurements of the several tassel dimensions, however, disclosed the fact that while the normal type of tassel, as represented by the Gordo variety, dominated the conical tassel of the *Ramosa* parent, nevertheless the Gordo type had undergone alteration, approaching more nearly the dimensions of the common maize tassel.

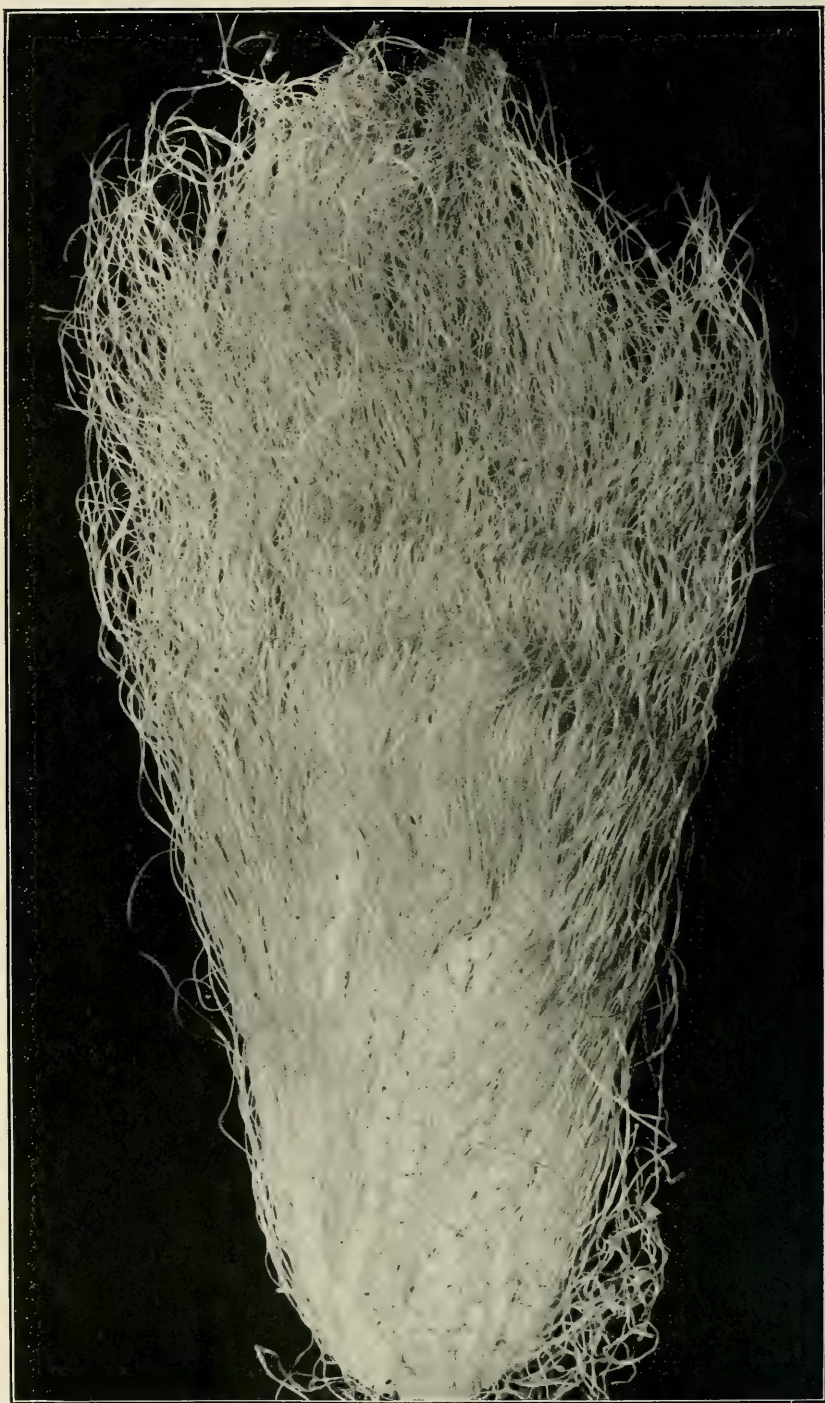
The vigor of the first generation was manifested in the size of the tassel, and the measurements of the several parts reflect this vigor. Thus, the length of the entire inflorescence exceeds that of the larger parent, and a subdivision of the inflorescence into the central spike and branching space shows that both of these parts have increased in length. This general increase in size prevents a direct comparison between the tassel dimensions of the F_1 and those of the parents, since the factor of heterosis can not be evaluated accurately. It would seem, however, that the length of the branching space, although less than the parental average, has been increased over that of the Gordo parent by a greater percentage than has the length of the central spike. This indicates the influence of the *Ramosa* parent, which would be expected to increase the length of the branching space at the expense of the length of the central spike.

A more direct measure of this effect is to be found in the central spike index. The index clearly shows that the proportion of rachis devoted to the production of branches has increased at the expense of the central spike, although the tassel is still of the normal type, the deviation toward the *Ramosa* parent being apparent only in the measurements. The measurements are given in Table I, and the frequency distribution of the central spike index are shown graphically in figure 1.



LONGITUDINAL SECTION OF A RAMOSE EAR OF MAIZE, SHOWING PROFUSE BRANCHING.

Such an ear when mature resembles that shown in Plate X. (Natural size.)



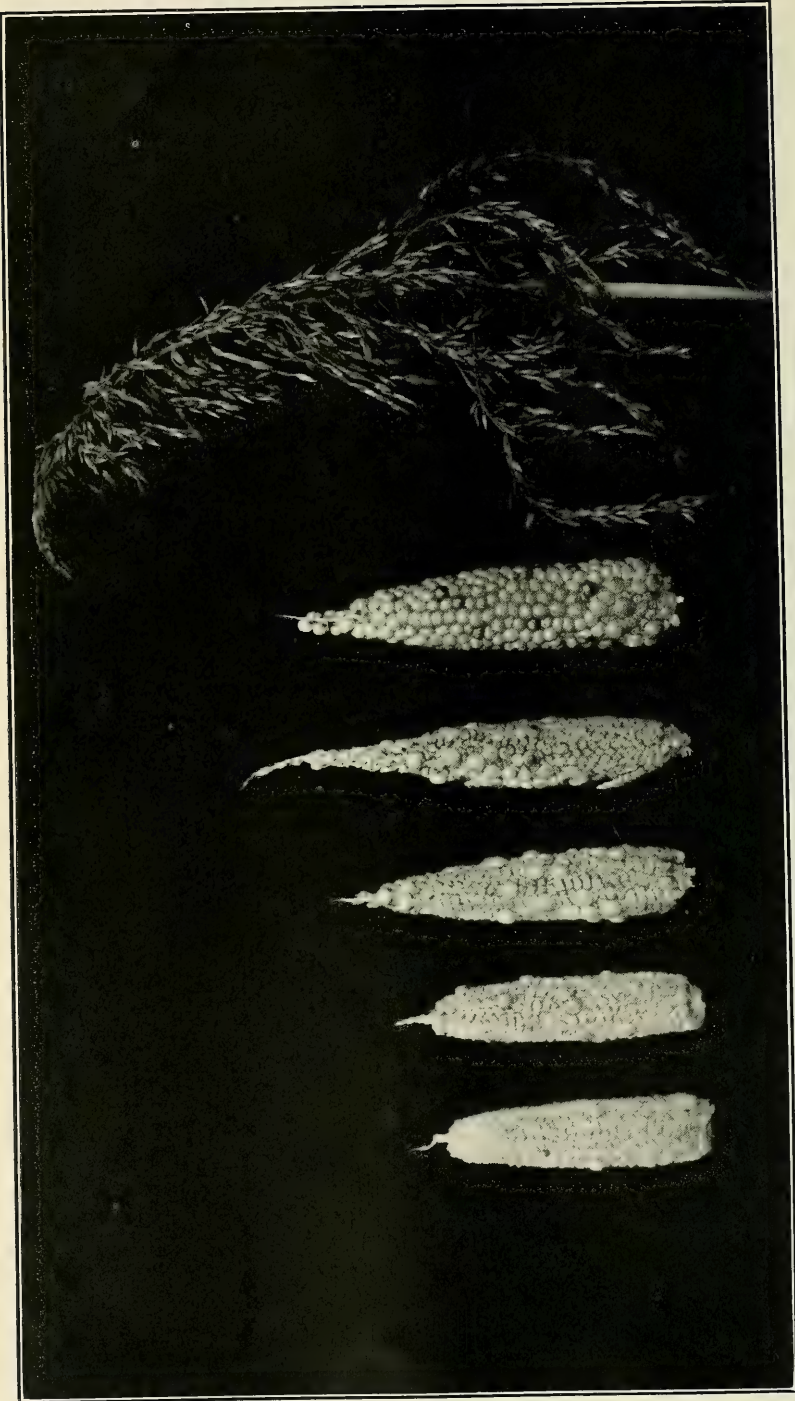
A RAMOSE EAR OF MAIZE, SHOWING PROFUSE SILKS.

The silks on this ear were determined by count to be 4,700. (Natural size.)



MAIZE PLANT, SHOWING THE TYPE OF TASSEL CHARACTERISTIC OF THE GORDO VARIETY.

The central spike of this tassel was 55 cm. long, while the spread from the tips of the branches was 80 cm.



TASSEL AND EARS FROM A SECOND-GENERATION PLANT OF A RAMOSA-GORDO MAIZE HYBRID.

The ear nearest the tassel is the uppermost, while the two farthest from the tassel were borne on tillers. Note the one small branch at the base of the second ear from the tassel.

SECOND GENERATION.

The ears of the first generation and, for that matter, the normal ears of the second generation provide no very good characters for a quantitative comparison with the parents, since the branches are suppressed. The plants of the second generation were grown from self-pollinated F_1 seed. No difficulty was encountered in classifying

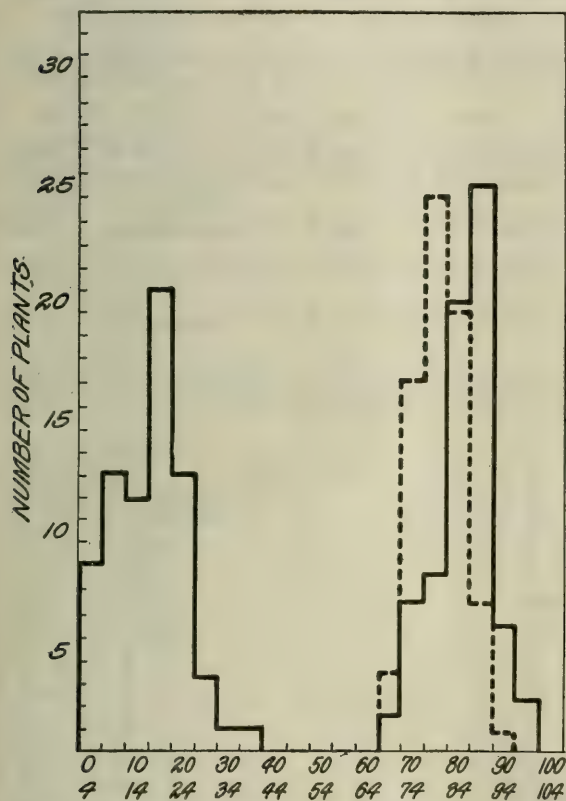


FIG. 1.—Frequency distributions with respect to the central spike index in maize plants of the Ramosa and Gordo varieties and of the first generation of this hybrid. Polygon at left, Ramosa; at right, Gordo; inclosed in broken line, first-generation hybrid.

tassels of the ramose plants are not, on the average, as ramose as those of the Ramosa parent, and likewise the tassels of the normal plants are not as extreme in form as those of the Gordo parent. This is shown graphically in the central spike index in figure 3. In each case the alterations are in the direction of the F_1 . Thus the ramose character, while behaving in a general way as a unit in inheritance, is capable of being resolved into several parts which behave in inheritance as multiple-factor size characters (Table I). The counts, based on the configuration of the tassel, gave 130 ramose and 399 normal, or 24.6 ± 1.3 per cent ramose.

them as to their ramose or normal nature from the standpoint of the tassel, and although it was apparent that the ramose tassels were variable, the conical configuration left no ground for reasonable doubt. Both the normal and the ramose segregates of the second generation showed the effect of hybridization, behaving in a manner entirely comparable with that commonly expected in size characters (fig. 2). Although the normal and ramose segregates of the second generation were easily distinguished, it is apparent from the measurements in Table I that the tas-

TABLE I.—Measurements of the tassel characters of the *Ramosa* and *Gordo* varieties of maize compared with those of the first and second generations of their hybrids.

Parental designation.	Measurements of length (centimeters).					Number of branches.	Central spike index.
	Entire.	Branching space.	Central spike.	Uppermost branch.	Lowest branch.		
Parents:							
Ramosa.....	32.6±0.37	27.7±0.32	5.0±0.23	1.8±0.05	20.7±0.31	133.7±3.69	15.5±0.58
Gordo.....	30.5±0.33	5.1±0.14	25.1±0.30	15.4±0.21	19.4±0.30	7.0±0.23	83.4±0.43
Combined F ₁ a.....	47.7	10.7	36.7	21.8	28.0	14.4	77.6
Combined F ₂ :							
Normal a.....	38.4	8.3	30.0	17.3	22.3	13.4	77.4
Ramosa a.....	33.5	21.7	10.3	3.1	17.6	58.9	30.8
Mh157 F ₁	47.1±0.48	10.7±0.28	36.3±0.55	22.0±0.39	26.7±0.51	17.4±0.83	77.0±0.74
Mh158 F ₁	48.6±0.33	10.8±0.16	37.6±0.28	22.2±0.26	28.4±0.30	11.8±0.30	77.7±0.30
Mh159 F ₁	46.0±0.43	10.5±0.23	35.6±0.30	21.2±0.38	28.1±0.45	16.6±0.44	77.9±0.57
Mh157 F ₂ :							
Normal.....	33.7±0.27	8.4±0.12	24.9±0.21	14.8±0.18	18.4±0.24	19.2±0.35	73.6±0.33
Ramosa.....	29.6±0.39	19.8±0.36	10.0±0.25	3.3±0.21	14.4±0.26	60.4±0.16	32.8±0.69
Mh158 F ₂ :							
Normal.....	40.3±0.39	8.0±0.26	32.4±0.55	18.3±0.46	23.4±0.55	10.0±0.37	80.1±0.62
Ramosa.....	35.2±0.50	24.3±0.57	10.7±0.30	2.9±0.11	18.6±0.46	55.2±1.51	30.5±0.79
Mh159 F ₂ :							
Normal.....	43.2±0.39	8.6±0.21	34.5±0.37	19.5±0.28	27.3±0.44	10.3±0.32	78.7±0.45
Ramosa.....	38.1±0.66	28.2±0.62	10.0±0.60	3.4±0.20	22.8±0.72	66.0±0.70	25.3±1.24

a The several progenies were combined for purposes of inspection only, and therefore the probable errors were not calculated. As a close inspection of the table will show, sister progenies differed in some characters by amounts too large to be ascribed to chance, and therefore the combined progenies do not constitute a homogeneous population.

When the ears were harvested the variability in the expression of the ramosa character was even more striking. Plants classified as ramosa from the characteristics of their tassels bore ears which ranged in a continuous series from unbranched cobs to the typical ramified inflorescence (fig. 4). The unbranched ear produced on a ramosa plant is shown in Plates IV and V, while some of the intermediate stages are shown

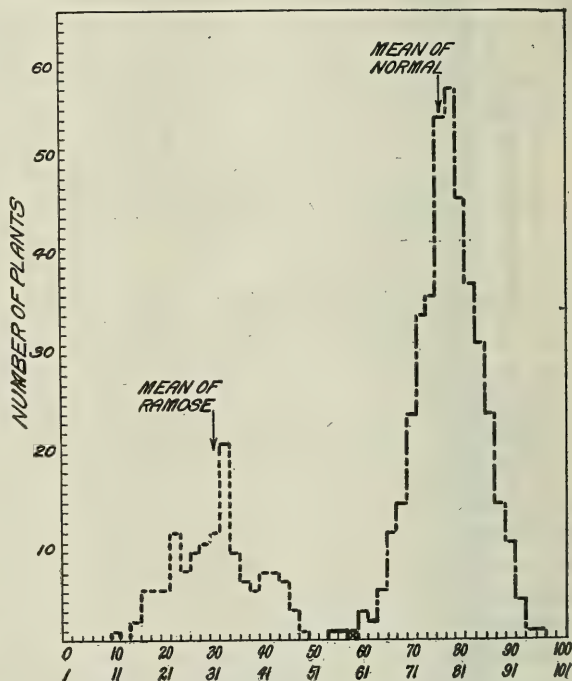


FIG. 2.—Frequency distributions with respect to the central spike index in maize plants of the second hybrid generation of Ramosa-Gordo. The square marked with a cross represents a plant classed as ramosa.

in comparison with a typical ramose ear in Plates VI to X. This series could be expanded by the addition of still other intermediate ears, but it is believed that these are enough to show the degree of variability.

CORRELATION OF THE EAR CHARACTERS OF THE SECOND GENERATION.

The correlations of the ear characters with the tassel characters for these F_2 segregates have been calculated and are summarized in Table II. The highest correlation found between the 5-ear and 4-tassel characters is that of 0.546 between the total number of branches on the ear and the same character of the tassel. The next highest correlation is -0.406 between the number of branches in the tassel and the terminal spike index of the ear. This index is in a sense complementary to the number of branches on the ear, the correlation between these two characters being -0.642 .

The only other significant correlation which does not comprise a measure of the number of tassel branches as one character is a rather unexpected correlation

of 0.398 between the lengths of pistillate and staminate inflorescences, which may be an indication of general vigor.

Among the ear characters the only significant correlations obtained which are not explained readily as being measures of the same characteristics are the coefficients of 0.756 between the number of

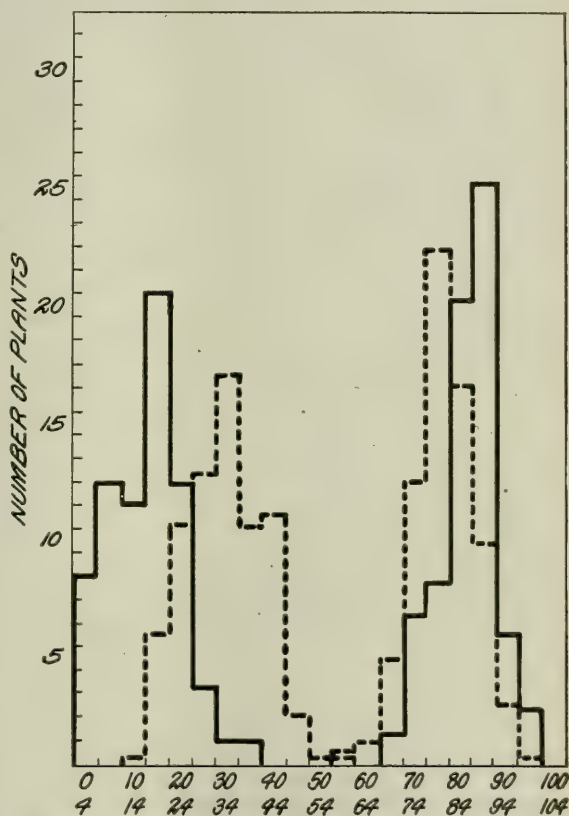


FIG. 3.—Frequency distributions with respect to the central spike index in maize plants of the *Ramosa* and *Gordo* varieties and of the normal and ramose segregates of their second-generation hybrids. Polygons inclosed in solid lines: At left, *Ramosa*; at right, *Gordo*. Polygons inclosed in dotted lines: At left, ramose segregates; at right, normal segregates. The populations of *Gordo* and of the normal and ramose segregates have been plotted on the basis of 69 individuals, to facilitate comparison with *Ramosa*.

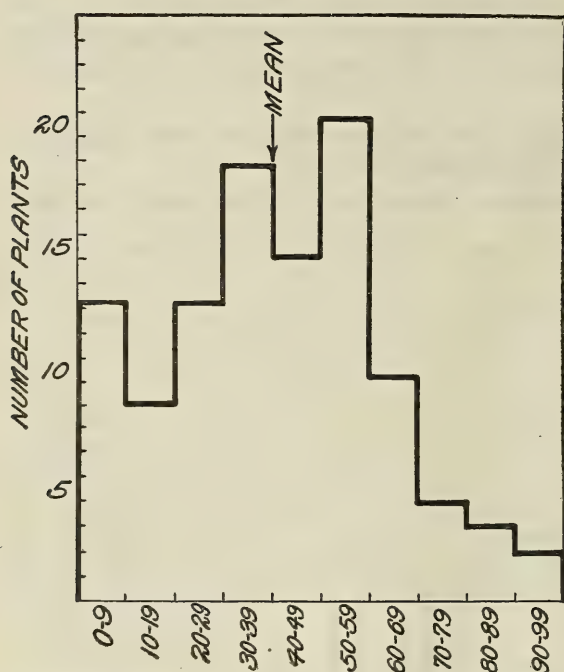


FIG. 4.—Frequency distributions with respect to the number of branches on the ear in plants of the second-generation ramose segregates of Ramosa-Gordo maize hybrids.

TABLE II.—Summary of the correlations between the ear and tassel characters in the second generation of Ramosa-Gordo maize hybrids.

[The population for which these coefficients were calculated consists of 102 individuals. Any coefficient greater than 0.196 exceeds three times the probable error.]

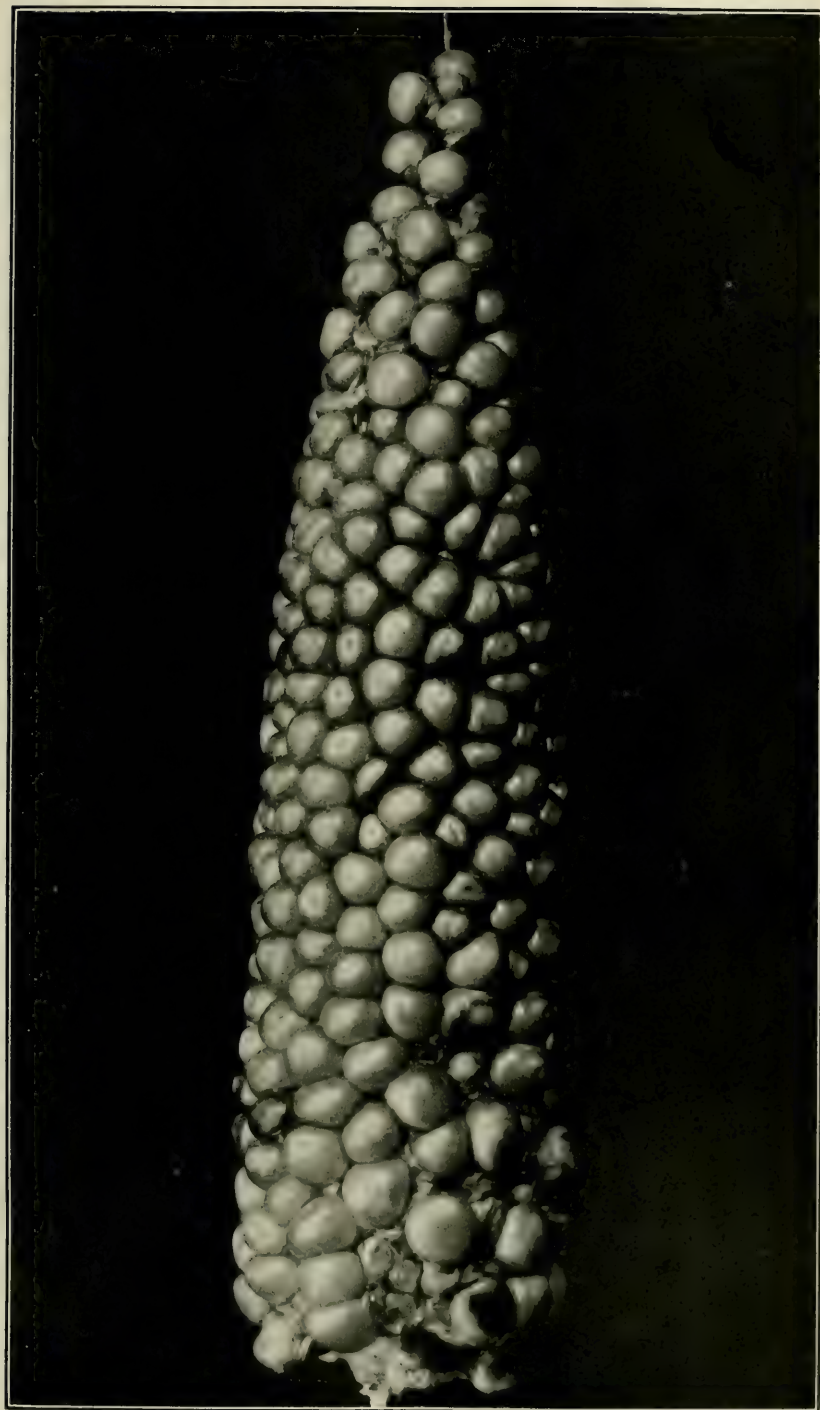
Character designation.	Branches on ear.	Number of rows on the central spike of the ear.	Length of terminal spike of the ear.	Length of the entire ear.	Ear spike index.	Length of tassel.	Length of the central spike of the tassel.	Number of branches in the tassel.	Central spike index.
Branches on ear.....	—	—0.472	—0.596	0.235	—0.642	0.055	—0.237	0.546	—0.291
Number of rows on the central spike of the ear.....	—0.472	—	.756	.300	.745	.147	.192	— .308	.156
Length of the terminal spike of the ear.....	— .596	.756	—	.391	.946	.163	.241	— .393	.154
Length of the entire ear.....	.235	.300	.391	—	.179	.398	.147	.035	— .103
Ear spike index.....	— .642	.745	.946	.179	—	.134	.212	— .406	.152
Length of tassel.....	.055	.147	.163	.398	.134	—	.407	.123	— .115
Length of the central spike of the tassel.....	— .237	.192	.241	.147	.212	.407	—	— .409	.811
Number of branches in the tassel.....	.546	— .308	— .393	.035	— .406	.123	— .409	—	— .503
Central spike index.....	— .291	.156	.154	— .103	.152	— .115	.811	— .503	—

THIRD GENERATION.

The appearance at harvest of markedly intermediate ears associated with intermediate tassels indicated that intermediate forms

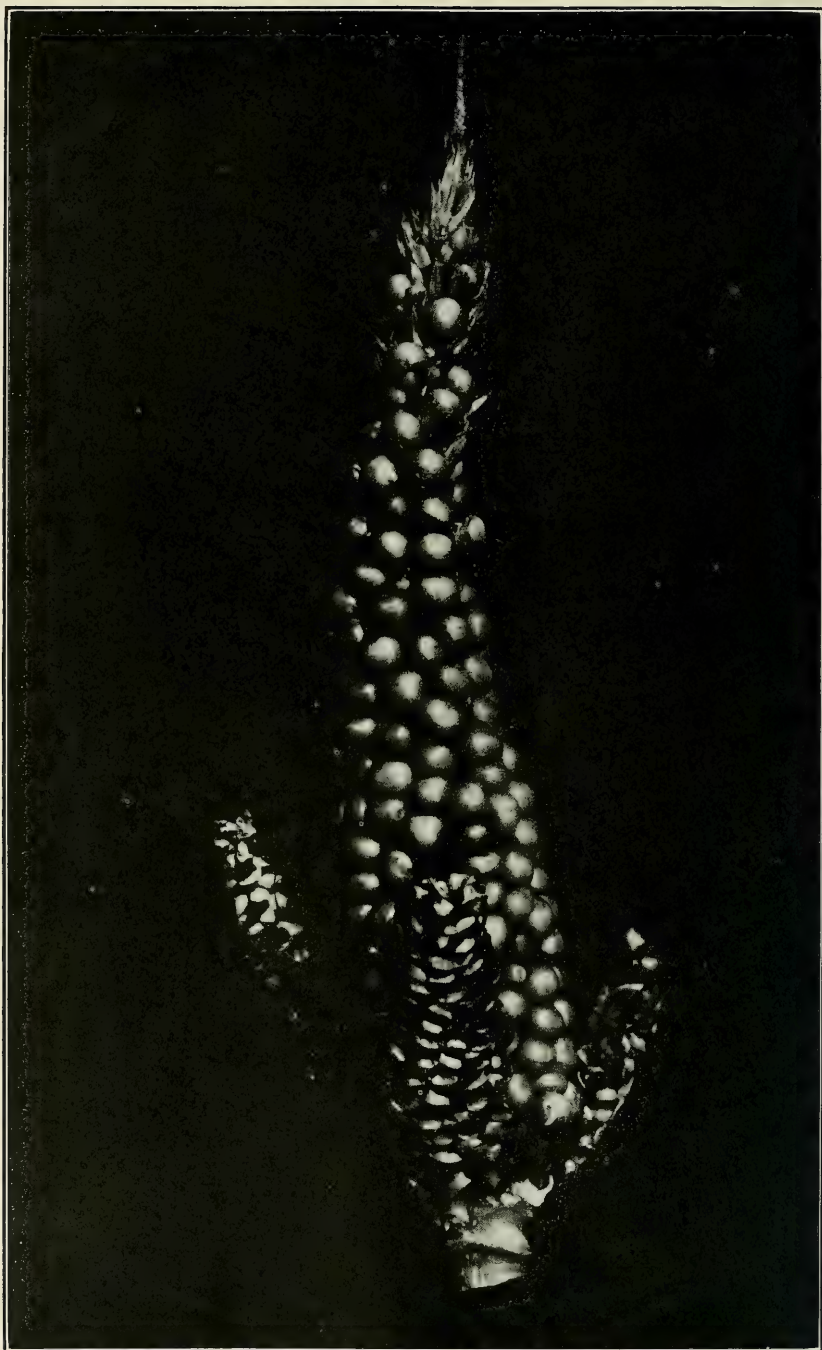
rows and the length of the ear spike and -0.472 between the total number of branches and the number of rows. Both coefficients indicate that as the central axis approaches a normal ear in length it also resembles a normal ear in the number of rows.

Among the tassel characters no correlations are found which are not capable of obvious explanation. Thus big tassels have long central spikes, while the longer the central spikes the fewer the branches.



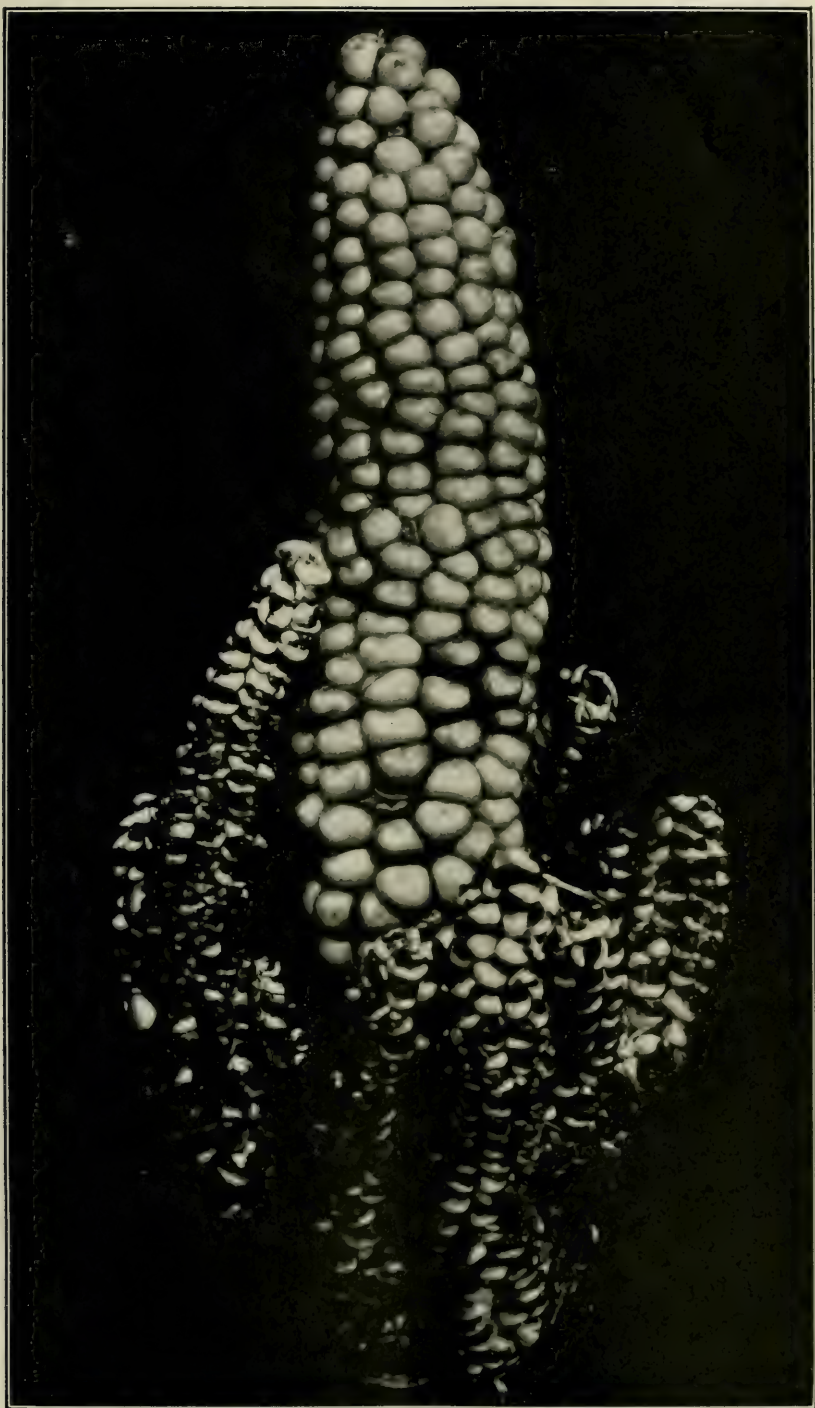
AN UNBRANCHED EAR OF THE SECOND GENERATION OF A RAMOSA-GORDO
MAIZE HYBRID.

The tassel of the plant which bore this ear was classified as ramose. (Natural size.)



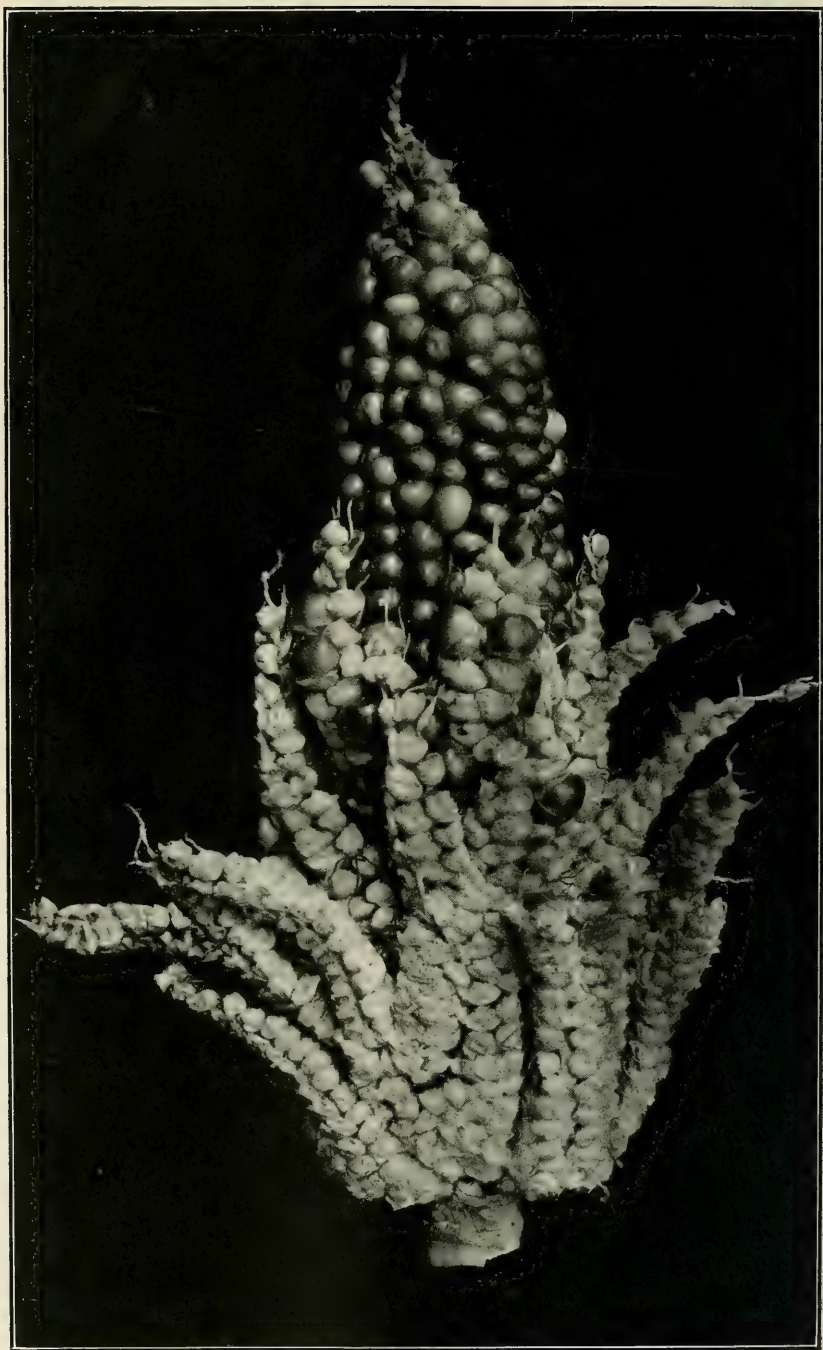
AN INTERMEDIATE RAMOSE EAR FROM THE SECOND GENERATION OF A
RAMOSA-GORDO MAIZE HYBRID.

There is a gradual loss in the number of rows of spikelets from the base to the tip. The
branches on this ear have eight rows of spikelets. (Natural size.)



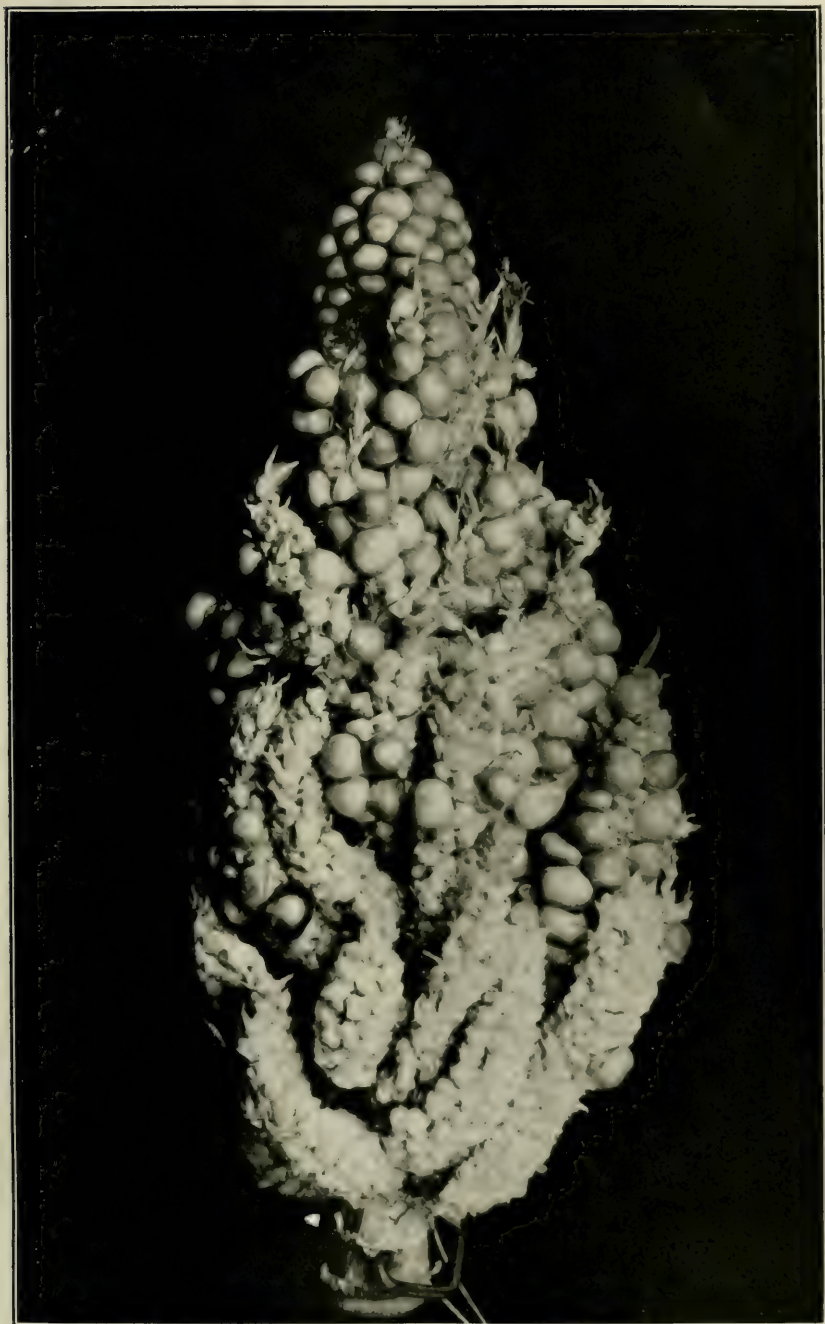
AN INTERMEDIATE RAMOSE EAR OF MAIZE WITH WELL-DEVELOPED
CENTRAL AXIS.

The branches on this ear have eight rows of spikelets. (Natural size.)



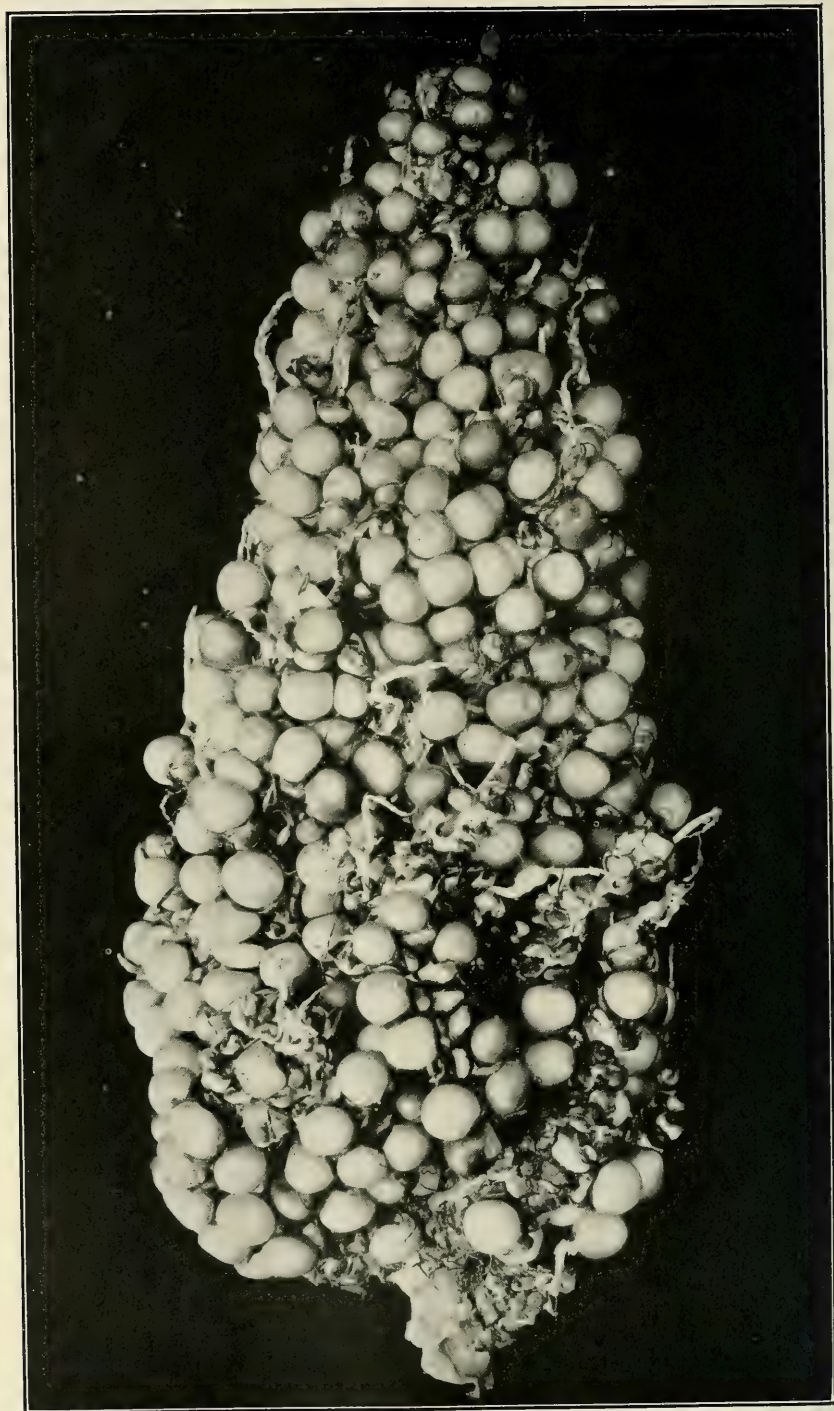
AN INTERMEDIATE RAMOSE EAR FROM THE SECOND GENERATION OF A
RAMOSA-GORDO MAIZE HYBRID.

Compare with Plate X. (Natural size.)

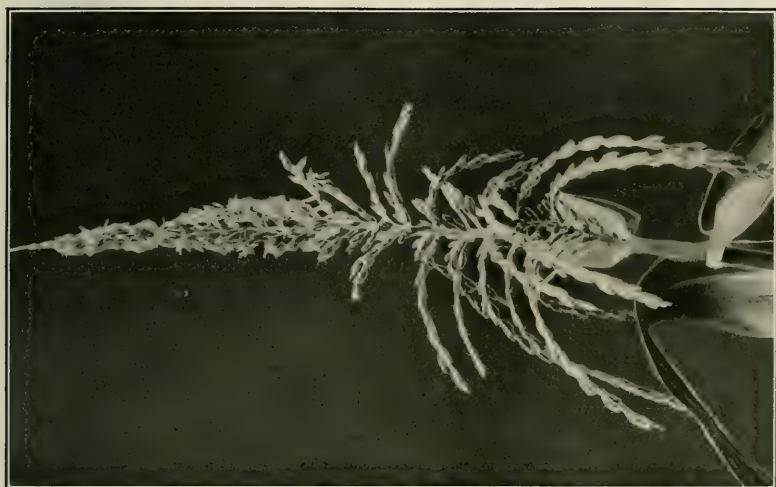


AN EAR PRODUCED IN THE SECOND GENERATION OF THE RAMOSA-GORDO
MAIZE HYBRID.

The development of branches here shown is not much inferior to a typical ramosa ear.
(Natural size.)



A TYPICAL RAMOSE EAR OF MAIZE, SHOWING THE ARRANGEMENT OF THE SEEDS.
(Natural size.)



TWO FORMS OF INTERMEDIATE RAMOSE TASSELS FOUND IN THE FOURTH GENERATION OF A RAMOSA-GORDO
MAIZE HYBRID.

The tassel at the left is typical of several progenies. Neither plant had branches on the ears.



SECTION OF THE CENTRAL SPIKE OF THE TASSEL FROM A PLANT OF THE THIRD GENERATION OF A RAMOSA-GORDO MAIZE HYBRID.

The spike here shown is of an intermediate ramosa type. (Natural size.)

of the ramose character could be established. Since no further generations were contemplated at the time of flowering, none of the second-generation plants was hand-pollinated. In order to test the possibility of isolating intermediate strains, two open-pollinated ears were saved for planting. Both ears were grown from and had a preponderance of white seeds, indicating that little cross-pollination had taken place, since most of the adjacent sister progenies were producing yellow seeds. One ear was unbranched and the other had only four basal branches, but both were from plants which produced obviously intermediate ramose tassels, as is shown in Table III in comparison with the tassel measurement of their *Ramosa* parent.

TABLE III.—*Tassel measurements of the Ramosa parent compared with those of two plants having branched and normal ears selected from the third generation of maize hybrids.*

Form of ear.	Measurements of length (centimeters).				Number of branches.	Central spike index.
	Branching space.	Central spike.	Upper-most branch.	Lowest branch.		
Ramose.....	27.7	5	1.8	20.7	133.7	15.5
Unbranched.....	29	7	3	24	68	19
4-branched.....	20	11	3	22	63	35

From the unbranched ear 23 plants were raised, 13 of which produced ears with branches ranging in number from 2 to 35, but none approaching a typical ramose ear. These branched ears, as well as some of the unbranched ones, were produced by plants that had tassels intermediate between normal and ramose. Some of the plants with unbranched ears obviously were hybrids with normal plants, but the ears of others could be classed definitely as resembling the parental unbranched ear.

Grown as progeny of the 4-branched ear were 19 plants, and of these 7 were branched, 1 being a good ramose, while the other 6 had from 3 to 15 branches. In this progeny, as in the other, tassels intermediate between ramose and normal were found.

FOURTH GENERATION.

Of the 42 plants in the third-generation progenies, 18 were self-pollinated and progenies were grown from them. These 18 plants varied in the number of branches on the ear from none to a typical ramose inflorescence. All of the plants showed unmistakable signs of their *Ramosa* ancestry in the form of the tassel (Pl. XI). The measurements of the F_4 plants are given in Table IV.

TABLE IV.—Comparison of the staminate and pistillate inflorescences of the fourth generation of the *Ramosa-Gordo* maize hybrid *Mh158*.

Parental designation.	Measurements of tassel length (centimeters).					Number of branches.		Central spike index.
	Entire	Branching space.	Central spike.	Uppermost branch.	Lowest branch.	Tassel.	Ear.	
L2L1L1.....	37.6±0.64	20.2±0.41	17.4±0.59	4.6±0.18	26.3±0.60	43.4±1.27	3.5±0.62	45.6±1.14
L2L1L2.....	41.6±0.79	20.7±0.56	20.8±0.87	6.9±0.53	23.6±0.64	23.2±1.5	0	49.6±1.9
L2L1L3.....	41.1±0.80	24.1±0.63	16.1±0.66	5.3±0.21	25.8±0.63	48.4±2.1	5.5±0.65	39.0±1.18
L2L1L4.....	34.3±0.58	15.8±0.58	18.7±0.51	5.1±0.28	21.5±0.52	23.0±1.35	0	54.7±1.36
L2L1L5.....	35.5±0.60	21.9±0.31	13.5±0.53	4.4±0.26	17.3±0.58	41.2±1.12	3	37.6±0.97
L2L1L6.....	41.4±0.72	17.5±0.66	23.9±0.66	8.4±0.55	28.2±0.58	22.2±1.46	0	57.8±1.43
L2L1L7.....	31.5±0.71	22.2±0.53	9.2±0.41	3.2±0.69	16.8±0.64	48.3±1.66	14.1±5.84	29.2±1.37
L2L1L8.....	37.5±0.52	25.3±0.47	12.0±0.50	4.1±0.20	21.0±0.61	54.2±1.90	9.5±1.05	32.0±1.16
L2L1L9.....	32.5±0.55	21.5±0.45	11.0±0.42	4.0±0.19	16.0±0.50	41.7±1.47	4.5±0.87	33.7±1.06
L2L1L11.....	35.2±0.62	19.6±0.53	15.6±0.44	5.8±0.33	17.6±1.44	39.2±1.32	7.9±1.19	44.4±1.13
L2L1L12.....	37.9±0.69	22.2±0.74	15.6±0.69	5.4±0.28	23.8±0.65	36.0±1.70	2.3±0.62	41.1±1.68
L2L2L1.....	40.8±0.67	15.7±0.69	25.1±1.13	13.4±0.88	24.2±0.93	32.2±1.67	.....	60.0±2.12
L2L2L2.....	32.7±1.10	17.7±0.72	14.6±1.12	5.2±0.37	14.4±0.58	30.2±1.53	3.9±0.89	43.9±1.48
L2L2L3.....	33.0±0.92	22.4±0.68	10.4±0.63	5.5±0.41	18.5±0.35	52.3±1.93	11.2±1.06	30.9±1.51
L2L2L4.....	31.0±0.63	17.9±0.49	13.0±0.68	4.2±0.14	18.0±0.60	50.4±2.13	.....	41.8±1.40
L2L2L5.....	29.4±0.75	15.5±0.37	13.9±0.53	4.5±0.24	16.8±0.42	25.2±1.06	6	47.0±1.26
L2L2L6.....	26.7±0.89	12.5±1.04	14.2±0.80	4.5±0.29	13.4±0.53	22.3±2.16	3.6	53.6±2.53

The distribution of the F_2 , F_3 , and the F_4 plants for branches on the ear is shown in Table V, and the distribution for the branches on the tassel in Table VI. The number of branches on the ear is the best single quantitative expression for the degree of branching, although subject to a certain variation due to variation in the size of the whole inflorescence.

In Table VI the positions of the parent plants are shown by plus marks. The positions of plants which bore ramose ears are shown by italic figures; where there were two such plants only one of them bore a ramose ear except in a single instance (marked with a star at line 54, column 38) wherein two plants bore ramose ears.

In the tassels of the F_4 the difficulty of giving a single expression for the degree of branching is much greater. This may be due to the larger size of the staminate inflorescence, which tends to emphasize the variability by magnifying small differences. The total number of tassel branches is, of course, reduced on plants of low vigor, and in a general way this may be reflected in a reduction in the size of the entire inflorescence, though the correlation between the size of the tassel and the number of branches in the ramose segregates of the F_2 is but 0.123 ± 0.066 . The best indication of the ramose character is the general form of the inflorescence, which is difficult to reduce to a single expression. Thus, in one F_4 progeny many of the plants developed in addition to the usual basal branches one or two branches midway in what otherwise was a normal central spike (Pl. XII). In some of these plants also the pedicels of the paired spikelets gradually increased in length toward the base of the central spike, giving this organ a pronounced conical shape (Pl. XI). Neither the num-

ber of branches, the length of the branching space, nor the central spike index would measure properly such behavior, as all would approximate closely the dimensions of a normal tassel.

TABLE V.—*Distribution of plants of the second, third, and fourth generations of the Ramosa-Gordo maize hybrid Mh158 for the number of branches in the ear.*

[The distribution in the second generation is for ramose plants only. The position of the parental ear is indicated either by italic figures or by a plus mark. R indicates ears classed as ramose, since the number of branches exceeded 50.]

Branches per ear.	Progeny distribution differentiated by parents (number of plants).																
	L2 F ₂ .	L2L2F ₃ .	L2L2L1 to 6 F ₄ .						L2L1F ₃ .	L2L1L1 to 11 F ₄ .							
		4	0	3	7	9	15	R	0	0	0	0	0	0	3	3	4
0.....	1	12	16	1	15	2	...	4	10	26	22	23	9	1	23	2	...
1.....	1	...	...	1	2	1	...	2	...	...	...	2	2	2	...	...	8
2.....	1	...	...	2	2	...	...	2	...	...	...	3	1	2	...	4	4
3.....	3	1	...	+	1	2	1	2	...	...	...	3	3	...	+	2	1
4.....	3	1	1	1	...	3	1	1	...	...	...	1	1	...	...	2	1
5.....	...	...	...	1	1	...	1	1	...	...	...	...	...	1	1	2	2
6.....	...	1	...	1	...	1	1	1	...	...	...	...	1	...	2	2	1
7.....	...	1	...	+	1	1	...	...	...	...	...	...	1	2	2	2	1
8.....	2	...	...	...	2	...	...	...	...	...	...	...	...	...	2	1	...
9.....	2	1	...	...	+	...	...	...	...	...	...	...	1	...	2	1	1
10.....	...	1	...	1	...	...	...	...	...	...	...	...	...	1	...	2	1
11.....	1	...	...	...	...	2	...	...	1	...	...	...	...	1	...	...	+
12.....	1	...	...	...	...	...	2	...	1	...	...	...	...	...	4	...	...
13.....	...	...	...	...	...	2	...	...	...	...	...	...	1	...	...	...	1
14.....	...	...	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...
15.....	1	1	...	...	...	+	...	...	...	...	...	...	1	...	2	1	...
16.....	1	1	...	...	...	1	2	...	...	...	...	...	...	1	...	1	2
17.....	1	1	...	...	...	...	...	...	1	...	...	...	1	...	...	...	+
18.....	1	1	...	...	...	1	...	...	...	...	...	...	1	1	...	...	...
19.....	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
21.....	2	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	1
22.....	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2	...
23.....	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1
24.....	1	1	...	1	...	...	1	...	...	...	...	...	...	...	...	...	...
25.....	1	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
26.....	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
27.....	1	1	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...
29.....	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
30.....	5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
32.....	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
33.....	3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
35.....	3	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	...
36.....	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
38.....	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...
39.....	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
40.....	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
41.....	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
42.....	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
43.....	3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
44.....	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
45.....	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
46.....	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
47.....	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
48.....	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
49.....	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
50.....	3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
R.....	35	1	4	1	...	1	2	1	...	...	...	...	3	...	...	5	12

The F₄ progenies demonstrate the possibility of isolating true-breeding intermediate forms, though the progenies differed among themselves in the degree of branching, viewed either from the standpoint of the tassel or from that of the ear. Nine of the progenies produced some plants with typical ramose ears, one progeny having as many as 12 plants with ramose ears in a population of 20.

Although this same progeny also had a relatively large number of tassel branches, it was exceeded in this character by four other progenies. Two progenies produced a total of 48 plants, all with unbranched ears, though both progenies bore unmistakable evidences of their *Ramosa* ancestry, possibly most marked in the staminate inflorescence, but apparent also in the form of the ears. It seems not unreasonable to predict that subsequent generations of these two progenies will continue to produce unbranched ears, though a relatively few plants with poorly developed ear branches may be expected for a few generations. It is difficult to believe that these progenies will ever give rise to typical *ramose* ears.

A typical *ramose* ear was produced on a plant that had but 32 tassel branches with a central spike index of 47, while an unbranched ear was borne on a plant with 57 tassel branches and having a central spike index of but 39. Thus, it is seen that extreme branching of one inflorescence is not associated inseparably with an extreme condition in the other, although in Gernert's original mutation the *ramose* characteristics of both inflorescences invariably appear together.

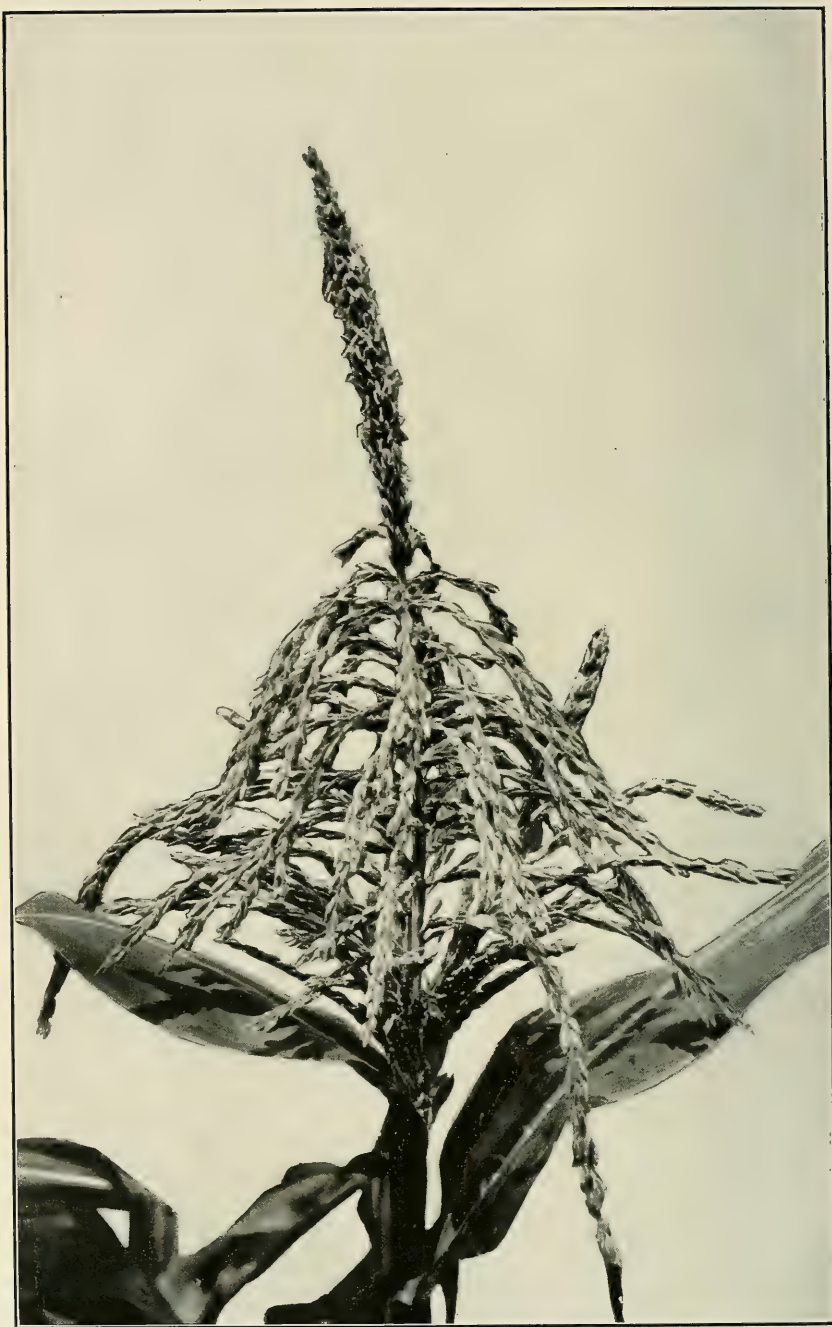
TABLE VI.—*Distribution of plants of the second, third, and fourth generations of the Ramosa-Gordo maize hybrid Mh158 for the number of branches in the tassel.*

Tassel branches.	Progeny distribution differentiated by parents (number of plants).																		
	L2F ₂ .	L2L2F ₃ .	L2L2L1 to 6 F ₄ .						L2L1F ₃ .	L2L1L1 to 11 F ₄ .									
		49	7	12	16	25	37	44	68	23	35	36	38	48	54	78	82	87	97 ?
3.														1					..
5.								1											..
6.		1							1										..
7.		3	+																..
8.														1					..
9.											1			1					..
10.								1			1								..
11.		1			1					4				2					..
12.		2	+						1	3									..
13.		1			1			1	2						1				..
14.		1						1	2	2									..
15.	1																		1
16.	1	1			+	1	1	1	2					1					..
17.				2										2					..
18.				1				1	1	1									..
19.				1					1	1	1			4	1				..
20.		2			2		1	1		1	1	1		3					3
21.				1						2	2			1				1	..
22.					3		2											1	..
23.				2	1		1	1	1	+								1	1
24.	1			3		1				1		1				1	1		1
25.		1			1	+	2	1			1			1					..
26.				3	1			1			1				1				2
27.				1	1		1			1									..
28.				1	2	1	1	1	1	1	1			1	1			2	1
29.				1		1		1		2						1	1	1	2
30.													1	1		1			..
31.				1	3						1							1	1
32.					2						1	2	1					1	1
33.	1			1		1	3	1				1	1	3	1	1		1	1
34.								1							1			1	1
35.	2				1	1				1	+	1	1			1		1	2
36.		2		1				1				+	1			1		1	2
37.	1	1						+								1		1	1
38.	1								1	1			+		2	1	1	1	..



A TYPICAL RAMOSE TASSEL OF MAIZE.

This tassel is from a plant of Mr. Mack's Yellow Evergreen variety. Compare with Plate XIV, showing an intermediate form.



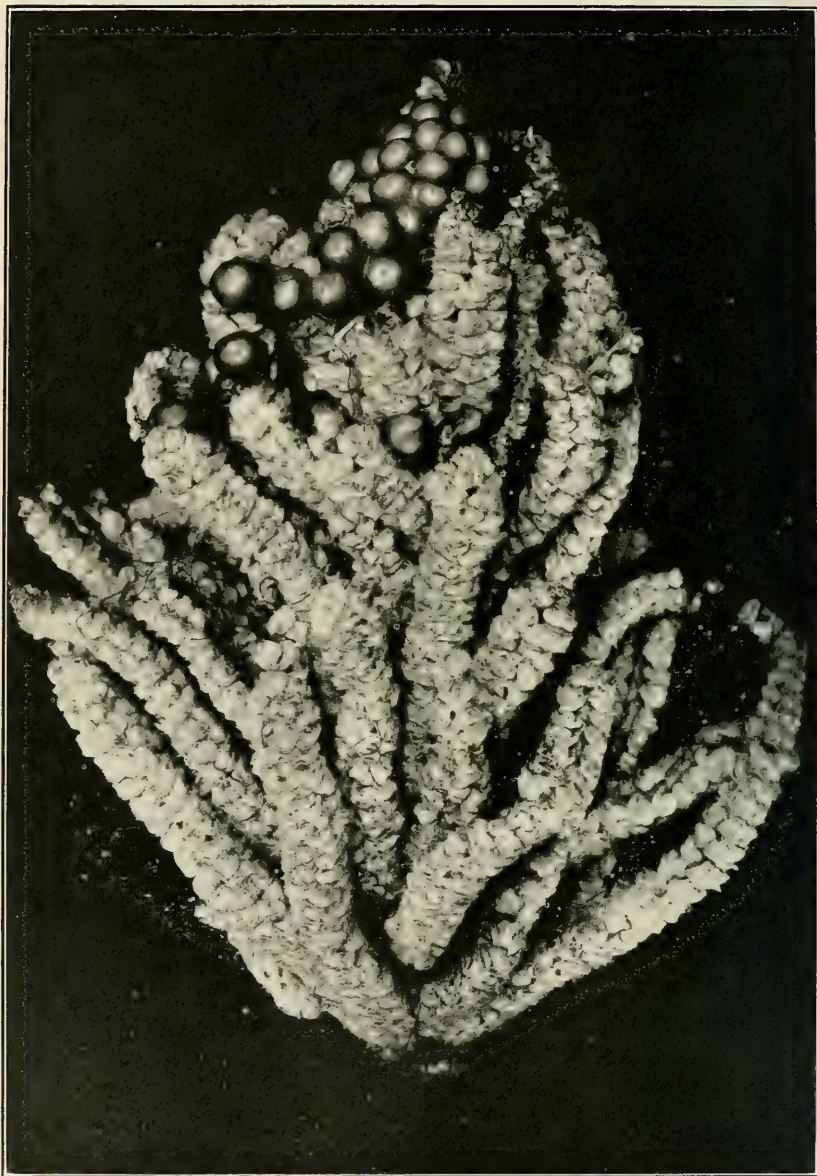
AN INTERMEDIATE RAMOSE TASSEL FROM MR. MACK'S SWEET-CORN VARIETY.

Compare with Plate XIII, showing a typical ramose tassel.



TWO BRANCHED EARS OF MAIZE.

The ear at the left is from the second generation of a *Ramosa-Gordo* hybrid, while that at the right is from a nonramose stock from the Pawnee Indians. (Natural size.)



AN INTERMEDIATE RAMOSE EAR FROM THE SECOND GENERATION OF A RAMOSA-GORDO MAIZE HYBRID.

The long branches shown have 8 and 10 rows of spikelets. (Slightly reduced.)

TABLE VI.—*Distribution of plants, etc.—Continued.*

Progeny distribution differentiated by parents (number of plants).																					
Tasselbranches.	L2F ₂ .	L2L2F ₃ .	L2L2L1 to 6 F ₄ .						L2L1F ₃ .	L2L1L1 to 11 F ₄ .											
		49	7	12	16	25	37	44	68	23	35	36	38	48	54	78	82	87	97	?	
39	1	1				2			1				1			1	4	1	1		
40	2			2	1	1				1	2			4	1	3	1	1	2	1	
41	1		1	1							3	1			2	1	1	1	1	1	
42		3				1				1				1	2		1	1	2	1	
43						1				1	1			1	1	3	1	1	1	1	
44	1	1						+				2			1	1	1	1	2	1	
45	1					1					1	1	1		3	1	1	1	1	1	
46							1	1		1	1					1	1	1	1	1	
47	1			2					1			2	2			2	1	1	2	1	
48		1		1			1	1						+	2	1	1	2	1	1	
49	2	+		2	1								2		1		2	1	2		
50	1			1	1				1								1	1	1		
51	2											1	1		1		1	1	1	1	
52	2											1	1		1		1	1	1		
53	1			1			1		1								1	1	1		
54	4			1					1				*		+	2	1	1	1		
55																					
56	2													1		1	1	1	1		
57	2			2			1	1								1	1	1	1		
58				1					1				1		1	2	1	1	1		
59	1	1		2												1	1	1	1		
60	1												1								
61	2			1											1					1	
62						1							2						1		
63	3					1			1				1				2				
64	1					1									1				1		
65	1																				
66						1											1				
67																					
68	1			1					+												
69	1												1								
70				1			1													1	
71	1																1				
72	1																1				
73	1																	1			
75						1															
76	1			1						1											
77	1																				
78									1								+				
81						1															
82	2								1							1	+				
83				1																	
85	1																				
87									2										+		
93	1																				
96									1												
97	2								1											+	
110									1												

DISCUSSION.

The simple Mendelian behavior of the ramoso character in the earlier experiments indicated that the present unbranched form of pistillate inflorescence and the reduced number of branches in the staminate inflorescence were the result of a single major genetic change. The variability of the ramoso segregates from the *Ramosa-Gordo* hybrids indicates that the evolution of the ear from a branched inflorescence was a gradual process. That the branching tendency of the staminate and pistillate inflorescences can be separated indicates that the two inflorescences did not undergo change at the same time, and from the general absence of branches on ears it would seem reasonable to infer that the transformation from

branches to spikelets first took place on the lateral inflorescences, the terminal inflorescences undergoing alteration later. However, it can not be stated definitely that the reduction of branches of the staminate and pistillate inflorescences is due to completely independent genetic changes. The fact that the ramoso variation as found had both inflorescences much branched and that they remain closely associated in most hybrids is an argument in favor of the hypothesis that the type of branching is constitutional with the plant and not restricted to particular inflorescences. If this were true, the ability to produce a highly ramified pistillate inflorescence on a plant with but little more than a normal number of branches in the staminate inflorescence would be attributed to genetic changes that have taken place since the original suppression of branches.

In this connection it is of interest to note the experience of Mr. J. M. Mack, of Fall Brook, Calif., who for 11 years has been unsuccessfully attempting to eliminate the ramoso type of ear from a variety of sweet corn. The ramoso variation made its appearance in

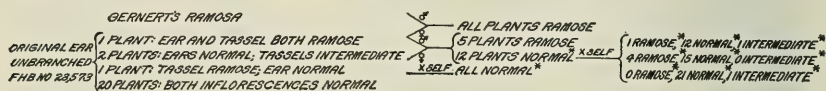


FIG. 5.—Diagram showing the pedigree of Mack's Yellow Evergreen sweet corn. Classifications marked with an asterisk (*) are based on the ear characteristics; most of the normal plants had intermediate tassels.

Mr. Mack's stock in 1909, three years before its discovery by Gernert. Undoubtedly both strains originated independently, though crosses have proved them to be genetically identical. The seed of this sweet corn, used in experiments by the Office of Acclimatization and Adaptation of Crop Plants, was received from the Office of Seed and Plant Introduction, United States Department of Agriculture, FHB No. 23573, in March, 1917. Some of the plants grown from the seed in 1918 were found to have typical ramoso tassels (Pl. XIII), while others showed a well-marked intermediate stage (Pl. XIV), the whole progeny with respect to the tassel falling into three fairly distinct groups of 17 normal, 2 intermediates, and 2 ramoso. When the ears were harvested it was found that none of the intermediate or normal plants bore branched ears, and only one of the ramoso plants bore a branched ear, but this was a typical ramoso ear. The ears borne on the plants with intermediate ramoso tassels showed no indication of the ramoso character, the rows being regular, the pedicels short, and the ears only moderately tapered. The intermediate tassels differ from those developed in the Ramosa-Gordo hybrids in that the only trace of Ramosa is the short central spike accompanied by the rather large number of branches (Pl. XIV).

It was found on a visit to Mr. Mack's gardens that the ramose plants were not being recognized until the ears were harvested. Thus, no selection was exercised against the ramose form of tassel except in so far as the two forms of inflorescence were associated. The result appears to have been an unintentional separation of the ramose ear from the characteristic ramose tassel. Even after 11 years of selection ramose ears appear occasionally and in combination with ramose tassels, but many more plants with typical ramose tassels and unbranched ears are found. The most common type of plant has a perfectly normal ear, while the tassel is intermediate between normal and ramose. Several self-pollinated progenies have been grown from these typical plants, and their pedigree is shown in figure 5. In a population of 55 plants, 5 produced typically ramose ears while 2 bore ears with branches only at the base—1 with an 8-rowed branch, the other with the common 4-rowed branches. Thus, in the apparently normal ears the ramose tendency may be manifested slightly. These branched ears have little in common with the branched ears developed in the *Ramosa-Gordo* hybrid, as they depart from the normal unbranched form only by the few branches. They resemble more closely a type of branching found in the *Pawnee* variety, and frequently in other varieties, the resemblance being so close as to suggest a relationship. The branched form of the *Pawnee* has remained unstable through three generations of self-fertilization, although the percentage of branched-ear plants has increased. The small number of branched ears in these intermediate strains of Mr. Mack's sweet corn seem to offer an entirely parallel case, and it may be justifiable to conclude that the *Pawnee* type of branched ear is simply a reduced stage of the ramose form.

Whether the intermediate forms of *Ramosa* isolated from the *Ramosa-Gordo* hybrid represent a series of multiple allelomorphs, multiple factors, or modifying factors remains an unsolved problem. The intermediate forms seem to be recessive to the typical *Ramosa*; at least a cross between a plant having an ear with 17 branches and a typical ramose plant gave fully ramose plants in the first generation. On the other hand, the progeny of the self-pollinated intermediate parent produced 11 ramose, 6 intermediate, and 2 unbranched ears. Results of this kind are disconcerting from the standpoint of simple analysis. About the only conclusion possible at this time is that true-breeding intermediate strains have been isolated having unbranched ears.

While many ears without branches are produced by the plants of the *Ramosa-Gordo* hybrids, they nevertheless exhibit other characteristics of their *Ramosa* ancestry which become more evident with a study of the intermediate forms. The seeds are borne on pedicels much longer than those of normal ears, and the abrupt taper with

the irregular rows is another indicative characteristic. The shape of these unbranched F_2 ears and also of many of the F_3 and F_4 intermediates strongly suggests the ears of a variety from the Canary Islands, the tassels of which have been noted as suggesting *Ramosa*. Other ears with 3 to 10 branches, similar to those found in Mr. Mack's variety, resemble the branched-ear variation of the Pawnee variety (Pl. XV). A similar type of branching has been found in the Texas Surcopper variety by Mr. W. W. Ballard and in the California Yellow Flint by Mr. C. G. Marshall. However, in these forms of branched ears from other than *Ramosa* stocks none has been found that had more than 4 rows of seeds on the branches, while on many of the *Ramosa* segregates the number of rows of spikelets on the basal branches is frequently 8 and sometimes as many as 10 (Pl. XVI). The gradation from typical *ramosa* ears to ears without branches affords evidence for the reduced-branched theory of the origin of the many-rowed cob (2), although in many of the ears the rows are extremely irregular and the abrupt taper from base to tip, with the consequent continuous reduction in the number of rows, militates against the development of the common cylindrical ear. Indeed, a study of these ears raises a serious doubt as to the possibility of developing our present regular-rowed ears through a reduction of lateral branches to pairs of spikelets. In many instances the intermediate *ramosa* ears clearly show that the branches reduce to a single spikelet instead of a pair, and in consequence each alveolus has but one seed; while the irregularity of the whole rachis precludes the possibility of determining accurately the number of rows, it is apparent that such ears could have an odd number of rows. The origin of the original *ramosa* variation in the Leaming variety is of interest in this connection, since one of the most constant characteristics of the Leaming variety is the poorly formed tip, which in many ears appears to have been artificially joined to the main portion.

It is difficult to visualize the common ear of maize as having arisen through the reduction of the branches of the inflorescences as they are now constituted, since there is little regularity in their present arrangement. If the branches of a normal maize tassel were reduced to paired spikelets, these spikelets would be arranged in a very irregular manner on the rachis and would bear little resemblance to the regular-rowed ears. If the reduction is assumed to have occurred at an earlier period when the branches of the inflorescence had a distichous arrangement similar to the present arrangement of the vegetative branches, the resulting ear would have but four rows, and the problem of their increase to the present number remains.

Hackel has explained the increase in the number of rows as the result of a coalescence of 4-rowed branches, a theory supported by numerous bifurcated and bear's-foot ears. Collins (3), in studying teosinte-

maize hybrids, found evidence that the number of rows was increased through a twisting of the rachis. Hackel's hypothesis of coalescence does not account for the arrangement of branches on the staminate and pistillate inflorescences of either ramose or normal plants. The *Ramosa-Gordo* hybrids furnish evidence that the present type of inflorescence developed through the reduction of branches which presumably occurred subsequent to the twisting of the rachis.

It is difficult, however, to account for the present complete differentiation of branching space and central spike in the staminate inflorescence on the theory of reduced branches, since it necessitates the assumption that the reduction ceased abruptly at about the midpoint of the staminate inflorescence, while it continued to the base of the pistillate inflorescence.

The frequent appearance of branched but nonramose ears where the pistillate inflorescence is more nearly of the form of the common staminate inflorescence strongly suggests that the loss of the basal branches followed rather than preceded the separation of the sexes.

If the view is adopted that the many-rowed spikes originated through the reduction of branches, it must be concluded that this reduction took place in two distinct periods. Thus, the upper two-thirds of the spike was developed through branch reduction, resulting in an inflorescence with a central spike and basal branches, a condition which was stabilized in the staminate inflorescences, while in the pistillate inflorescences the remaining basal branches have been reduced to spikelets or possibly entirely aborted. With this idea of the reduction of branches in restricted areas, it becomes possible to explain the bifurcated or bear's-foot ears by assuming that the reduction in branches began somewhat below the apex at a point corresponding to the place where the staminate spikelets first open. The branches above this point were reduced later, and the bear's-foot ear is a variation entirely comparable with the development of basal branches. In this connection it may be more than a coincidence that the branched-ear variation in Pawnee appeared simultaneously with a distinct bifurcation at the apex representing a reversion to the condition suggested in this hypothesis that the central section of the branches were the first to be reduced. In other words, the reduction in branches first took place on a central section of the rachis, leaving the tip and base branched, though the apical branches, of course, were short. These two sections were reduced later, and from the frequency of their reappearance it may be not unreasonable to infer that the branches of the tip were the last to go. On the other hand, if the change in the form of the pistillate inflorescence was entirely similar to that of the staminate inflorescence, the order of the disappearance of the branches must be reversed, since the basal branches of the staminate inflorescence have yet to be reduced except in the

most extreme form of the hairy *Esperanza* variety, where the tassel consists of a single spike having many rows of clustered spikelets.

The reduction of the branches of the staminate inflorescence involved only those branches that were finally eliminated, while the others remained unaltered. Thus, there was no general shortening of all the branches, resulting in the complete reduction of the short upper branches, but rather a definite change from branches to spikelets in the upper portion. This is illustrated in figure 6, where it is seen that the form of the present normal inflorescence would be almost exactly that of the ramose inflorescence if the upper branches of the ramose inflorescence were reduced without altering the re-

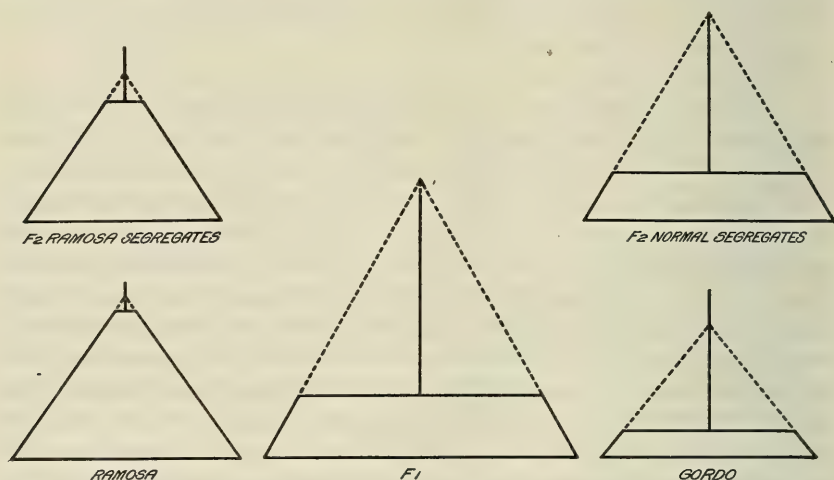


FIG. 6.—Diagrams showing tassel configurations of the first-generation plants and the normal and ramose segregates of the second-generation plants of *Ramosa-Gordo* maize hybrids. The solid vertical line represents in each diagram the length of the central spike, while the horizontal lines show the length of the lowest and the uppermost branches. The dotted lines show the projected angles formed by the lowest and uppermost branches.

maining branches, while it is equally apparent that the central spike of the Gordo variety has been elongated.

CONCLUSIONS.

The branched-ear variation designated *Zea ramosa* by Gernert has behaved generally as a simple Mendelian character recessive to the normal condition. In Gernert's variation the number of branches in the staminate inflorescence are increased greatly, and the configuration of the inflorescence is altered. This characteristic staminate inflorescence has always appeared in conjunction with the ramose ear, enabling the observer to detect the *Ramosa* plants in the field before examining the ears.

Crosses have been made between this ramose type and a type of maize from Mexico called Gordo, which has very few tassel branches,

departing from the common form in the opposite direction from that of the ramosa variation.

Although in a general way the Gordo type of staminate inflorescence is dominant to the ramosa form in the first generation of the hybrid, the influence of the *Ramosa* parent can be detected easily when the various parts of the inflorescences are measured. The ears of the F_1 were normal and without branches.

In the second generation of these hybrids the plants segregated into normal and ramosa plants. Classified from the general appearance of the tassel, approximately one-fourth of the plants were ramosa, supporting the results of previous investigations. Measurements of the various parts of the tassel showed, however, that the ramosa segregates had undergone alterations, having retained partially the characteristics of the Gordo parent, while conversely the normal plants showed the effect of their *Ramosa* ancestry.

In the ramosa group the general appearance of the tassels showed great variability. When the ears were harvested a similar range was observed. Plants classed as ramosa from the characteristics of the tassel had ears without branches, although the converse of this was not observed. Ears were obtained which ranged in an unbroken series from typical ramosa to those without branches. In a general way these intermediate forms of ears were associated with a similar intermediate condition of the tassel. An F_3 was grown from two open-pollinated ears, one without branches and the other with but four branches, both having tassels which betrayed their *Ramosa* parentage. The progeny of these plants ranged from typical ramosa to normal in respect to the ears, although most of the tassels were intermediate between ramosa and normal.

Eighteen F_4 progenies were grown from self-pollinated F_3 plants and showed that the diversity observed in the second and third generations was inherited. Two of the progenies produced only ears without branches, but the *Ramosa* ancestry was apparent in the tassels. These two progenies were both from unbranched ears. On the other hand, the progeny of a self-pollinated ramosa ear produced 1 typically ramosa, 11 intermediate, and 4 unbranched ears. It remains to be determined whether the modification of the ramosa variation is the result of introducing numerous modifying factors through the Gordo parent, or whether the ramosa character depends upon the combination of multiple factors for intense expression, or whether the true-breeding intermediate forms represent a series of multiple allelomorphs.

During the course of these experiments another ramosa variation has been found which is genetically identical with Gernert's variation, but this appeared three years earlier in the gardens of Mr. J. M. Mack, at Fall Brook, Calif. In this strain an intermediate

ramose condition is common, and occasionally plants have the typical ramose staminate inflorescences in combination with normal unbranched ears.

The appearance and behavior in inheritance of the intermediate ramose plants suggest a relationship with branched forms from non-ramose stocks and furnish evidences for the development of the single-spiked ear through a reduction of branches.

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JOHN R. MOHLER, Chief

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September 19, 1921

UNIT REQUIREMENTS FOR PRODUCING MARKET MILK IN EASTERN NEBRASKA.

By J. B. BAIN, *Dairy Husbandman*, G. E. BRAUN, *Market Milk Specialist*, Dairy Division, and E. A. GANNON, *Cooperative Investigator*, Nebraska Agricultural Experiment Station.

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CHARACTER AND SCOPE OF THE WORK.

How many pounds of grain, hay, and silage do dairymen feed to produce 100 pounds of milk in different sections of the United States? How many hours of labor do they expend? What other costs are involved? In 1915 the Bureau of Animal Industry, United States Department of Agriculture, began a series of studies on groups of dairy farms in different sections of the United States to obtain accurate information along these lines.

The project with which this bulletin deals was organized near Omaha, Nebr., in cooperation with the department of dairy husbandry of the University of Nebraska. The study was begun in September, 1917, but was discontinued at the end of the first year because of the resignation of the field man who was conducting it.¹

¹ C. H. Cook conducted the field work during the first year.

NOTE.—The work was carried on in eastern Nebraska in cooperation with the Department of Dairy Husbandry, University of Nebraska, and applies especially to milk shipped from that section to the Omaha market.

In September, 1919, the work was resumed and records were obtained for the second year. Thus there was an interval of one year between the two years in which the studies were made.

Although the figures obtained show what was required to produce milk for the Omaha market under the system of dairy management found in the section studied, and probably approximate the requirements in similar sections, they, of course, do not apply to dairying in sections where different conditions and methods of management prevail.

METHODS OF OBTAINING DATA.

The figures reported are based on actual records obtained by regular monthly visits of 24 hours each to 8 farms for two entire years and to 22 other farms for one entire year.

At the beginning and end of each year the field agent took an inventory of the dairy buildings, livestock, and equipment used in the care of the herd and its products. On his regular monthly visit at each farm the field agent, with watch in hand, noted and recorded the exact minute each labor operation on the dairy was begun and ended. An equally careful record was obtained of the kind, quantity, cost, and description of each feed fed. The quantity of milk sold and receipts each month were obtained. In addition the milk used by the proprietor and his help or fed to calves was measured or weighed on the monthly visit and used as a basis for determining the quantity kept on the farm during the month.

The dairymen kept itemized accounts of expenses incurred between monthly visits and reported these items to the field agent. Monthly records were kept of the purchase or sale of cows, calves, hides, the cost of outside bull service, and other miscellaneous information. Accurate records of calves born and first-hand information on the condition and methods of handling manure were collected systematically.

The records of all the herds for each month made it possible to obtain representative data for each month, season, and year. Records were obtained the second year as a check on the first year's work and to increase the quantity of data for study.

INFLUENCE OF SEASONS ON COST FACTORS.

The results have been reported separately for the winter and summer seasons because the season of the year may have a marked influence on the principal factors of cost. The months from November to April, inclusive, are considered as the winter season and the months from May to October, inclusive, as the summer season.

The various tables are based upon figures obtained during the two-year study, and the weighted averages of these records were

used wherever they would express the results more accurately. The weighted average was obtained by weighting each item according to its relative importance.

DESCRIPTION OF HERDS.

During the first year records were obtained on 21 herds containing a total of 268.2 cows, with an average yearly production of 5,806 pounds of milk testing 3.6 per cent butterfat. The second year's study included 226.5 cows in 17 herds, with an average yearly production of 5,843 pounds of milk and an average butterfat test of 3.7 per cent. Though most of the herds consisted of grade Holstein cows, there were a number of herds in which the Jersey and Guernsey breeds were well represented. The size of the herd was determined by the number of cows in the herd for 12 "cow-months." Cow-month is a term used to express the record of a cow in the herd for one month.

During the first winter, 43.6 calves were dropped for each 100 cows in the herds, and in summer the ratio was 42.5 calves. During the second winter 58.7 calves were born for each 100 cows kept, and in the second summer 44.2 calves were born. The total of 102.9 calves for each 100 cows for the year may appear excessive, but it is due to the fact that out of the 276 cows in the herd sometime during the year 49 were heifers that entered the herd when they freshened. Though in some cases these cows were in the herd only a few months, the herd was credited with their calves. Thus the herd received credit for the whole calf, whereas the dam was in the herd only a part of the year and was counted only as a proportionate fraction of 1. In this way the percentage of calves was materially affected. Combining the results for the two years, we have a total of 494.7 cows giving birth to 463 calves; or for every 100 cows there were 93.6 calves, 43 of these coming in the summer season and 50.6 in the winter season.

REQUIREMENTS FOR PRODUCING MILK.

The feed requirements are expressed in pounds, and labor in hours, in order to eliminate the effect of fluctuating prices. This method of presenting the facts makes it possible to use the figures for some time to come.

During the war many of the farmers in this section concentrated their efforts on raising grain, which forced dairying to occupy a secondary place. The high price of concentrates caused the dairymen to feed less grain, with the result that the production of the cows was less than it would have been under heavier feeding.

This fact is brought out by the record of a cow named "Prohibition." This cow was so named because she was always dry; at

least it appeared that way to her owner, since she would give milk for only five or six months and then go dry until the next freshening. When her owner found out from the first year's records that she had been dry for six months and had produced only 3,351 pounds of milk during the year, he decided that she should go to the stockyards at Omaha when she went dry again. So, as soon as the cow freshened, the owner began to feed her a little grain to keep her in condition so that it would not take so long to fatten her for beef after she went dry. But Prohibition did not go dry. With that extra grain she kept milking month after month, and at the end of the year she had 7,043 pounds of milk to her credit. The owner did not sell her, but he did change her name.



FIG. 1.—A barn typical of those on the farms studied.

A study of the original figures shows that grain was not fed so economically as it could have been. During the first winter one herd received only 3.8 pounds of grain for each 100 pounds of milk produced, while another herd received 82.5 pounds. Such a wide range in the quantity of concentrates fed was probably due to the fact that the dairy business is relatively new in this section and the most economical methods have not yet been generally adopted by the dairymen. Some dairymen in this section, however, are already following profitable methods of feeding and are giving their herds better care and improving them by breeding and selection. There was also a wide variation between the two winters and between the two summers in the quantity of grain and roughage fed. The wide

difference was accentuated by the fact that an entire year intervenes between the two years during which the records were taken.

The amount of human and horse labor was less than it would have been had the dairymen hauled their own milk. For the most part motor trucks were used to collect the milk and haul it to the Omaha market. The charge for this hauling appears in Tables 1 and 2 under the item "Cash hauling of milk." The item "Motor-truck charge" was payment for the service of a motor truck owned by a dairyman who hauled his own milk.

The cost of keeping a bull is expressed in dollars in Tables 1 and 2. In Table 5 the requirements for keeping a bull for one year are stated in units so that current prices for feed and labor may be applied.

The comparative size and importance of the various cash charges are shown in the lower section of Tables 1 and 2. For convenience the requirements for producing 100 pounds of milk and also for keeping a cow one year are tabulated separately.

TABLE 1.—Units required, except charge for management, for producing 100 pounds of milk in winter and in summer.

Item.	Winter.		Summa- ry of two winters.	Summer.		Summa- ry of two summers.
	1917-18	1919-20		1918	1920	
Feed:						
Purchased concentrates.....pounds..	7.0	0.9	4.4	1.4	0.9	1.2
Home-grown grains.....do....	37.9	35.4	36.8	9.1	10.7	9.8
Total concentrates.....	44.9	36.3	41.2	10.5	11.6	11.0
Hauling and grinding grain.....	\$0.007	\$0.028	\$0.016	\$0.001	\$0.007	\$0.004
Noncommercial roughage....pounds..	37.3	2.3	22.3	23.1	1.7	12.6
Commercial carbohydrate hay..do....	7.3	4.8	6.3	1.8	3.1	2.4
Commercial legume hay.....do....	29.1	116.8	66.7	47.2	24.9	36.2
Total dry roughage.....	73.7	123.9	95.3	72.1	29.7	51.2
Silage and other succulent roughage.....pounds..	104.9	78.5	93.6	40.2	18.0	29.3
Pasture.....	\$0.138	\$0.069	\$0.108	\$0.608	\$0.699	\$0.653
Bedding.....pounds..	11.0	11.1	11.1	.4	.6	.5
Labor:						
Human.....hours.....	2.1	1.9	2.0	2.2	1.6	1.9
Horse.....do.....	.03	.10	.06	.12	.03	.08
Other costs:						
Building charges.....	\$0.160	\$0.222	\$0.186	\$0.185	\$0.199	\$0.192
Equipment charges and dairy supplies.....	.084	.111	.096	.097	.100	.099
Herd charges: Taxes, insurance, veteri- nary service, medicines, and disin- fectants.....	.037	.024	.032	.043	.022	.033
Interest on cow investment.....	.119	.153	.134	.138	.137	.137
Cost of keeping bull.....	.098	.238	.158	.102	.145	.123
Motor-truck charge.....	.001	.....	.001	.005	.020	.012
Cash hauling of milk.....	.173	.190	.181	.167	.254	.209
Total other costs, except deprecia- tion on cows.....	.672	.938	.788	.737	.877	.805
Depreciation on cows.....	.122	.027	.081	.141	.024	.084
Total other costs.....	\$0.794	\$0.965	\$0.869	\$0.878	\$0.901	\$0.889

The summaries of the unit requirements by seasons are printed in bold-face type.

TABLE 2.—Quantities of various classes of feeds required and expenses incurred for keeping a cow during each season and for entire year.

Item.	Winter.	Summer.	Entire year.
Number of cows.....	497.1	492.3	494.7
Average production.....pounds..	2,938	2,885	5,823
Feed:			
Purchased.....do.....	129	34	163
Home-grown grains.....do.....	1,082	284	1,366
Total concentrates.....do.....	1,211	318	1,529
Hauling and grinding concentrates.....	\$0.48	\$0.12	\$0.60
Noncommercial roughage.....pounds..	656	363	1,019
Commercial carbohydrate hay.....do.....	183	69	252
Commercial legume hay.....do.....	1,959	1,045	3,004
Total dry roughage.....do.....	2,798	1,477	4,275
Silage and other succulent roughage.....do.....	2,749	844	3,593
Pasture.....	\$3.18	\$18.83	\$22.01
Bedding.....pounds..	325	15	340
Labor:			
Human.....hours.....	58.2	55.4	113.6
Horse.....do.....	1.9	2.3	3.2
Other costs:			
Building charges.....	\$5.48	\$5.53	\$11.01
Equipment charges and dairy supplies.....	2.81	2.84	5.65
Herd charges: Taxes, insurance, veterinary service, medicines, and disinfectants.....	.93	.94	1.87
Interest on cow investment.....	3.93	3.96	7.89
Cost of keeping bull.....	4.64	3.55	8.19
Motor-truck charge.....	.01	.36	.37
Cash hauling of milk.....	5.31	6.06	11.37
Total other costs except depreciation on cows.....	23.11	23.24	46.35
Depreciation on cows.....	2.38	2.40	4.78
Total other costs.....	25.49	25.64	51.13

CREDIT FOR CALVES.

The large credit of 1.02 calves per cow during the second year, as shown in Table 3, was due to many cows entering the herd at freshening time and remaining only a fractional part of the year. The effect of war prices is reflected in the larger average value of calves during the second year.

TABLE 3.—Total credit for calves produced, by years and by seasons.

Item.	Credit by years.		Credit by seasons.	
	1917-18	1919-20	Both winters.	Both summers.
Number of calves.....	231	232	250	213
Total value of calves.....	\$1,752.59	\$4,383.50	\$3,600.45	\$2,535.61
Average value of calves.....	7.59	18.89	14.40	11.90
Calves per cow.....	0.86 of 1 calf.	1.02 calves.	¹ 0.5 of 1 calf.	¹ 0.43 of 1 calf.
Credit per cow.....	\$6.53	\$19.35	¹ \$7.24	¹ \$5.15
Credit per 100 pounds of milk.....	0.01 of 1 calf.	0.02 of 1 calf.	0.02 of 1 calf.	0.01 of 1 calf.

¹ These figures are the averages for the respective seasons.

CREDIT FOR MANURE.

The method used in these studies for obtaining the value of manure takes into consideration the fertilizing constituents of the feeds. The proportion of the fertilizing constituents of the feed that was returned in the manure was obtained from standard tables. A cow digesting her feed utilizes on the average approximately 25 per cent of the nitrogen, 30 per cent of the phosphorus, and 15 per cent of the potash contained in the feed. It is evident, then, that 75 per cent of the nitrogen, 70 per cent of the phosphorus, and 85 per cent of the potash is voided in urine or in the solid portion of the manure. The urine voided by a cow is more valuable than the solid manure as a source of nitrogen and potash.

TABLE 4.—*Manure and fertilizing constituents credited to the herds during the two winters and the two summers.*

Item.	Winter.			Summer.		
	1917-18	1919-20	Average.	1918	1919	Average.
Total manure saved..... tons..	979.1	801.1	890.1	68.9	75.5	72.2
Manure per cow..... pounds..	7,062	7,289	7,162	532	647	587
Manure credited per 100 pounds of milk, pounds.....	234	256	244	19	22	20
Fertilizing constituents in manure, pounds.....	Winter average.			Summer average.		
	Nitro- gen.	Phos- phoric acid.	Potash.	Nitro- gen.	Phos- phoric acid.	Potash.
	8,426 33.9	2,599 10.5	8,753 35.2	683 2.8	210 0.9	710 3.0

The small credit for manure (Table 4) is due to a combination of factors. During the summer the cows are in the barn just long enough to be milked. Only during very cold or stormy days in winter are the cows kept in the barn. On other days they are permitted to run in the stalk fields, where they pick up a little corn and such roughage as they can find. On many farms a considerable quantity of the manure voided in the barns, especially the liquid portion, was lost through leaky gutters. When it was stored in the yards before being spread on the fields a large percentage of the fertilizing value was lost through seepage and exposure to the weather.

Only the manure that was dropped directly on the stalk fields, or was saved, or could have been saved by using reasonable care with the equipment available, was credited to the cows. The quantity of manure dropped was approximated by keeping a record of the time the cows were actually in the barn. This made it possible to

figure the weight of the manure voided in the barn, for, according to the best authorities, a 1,000-pound cow produces 13 tons of manure in a year, or $6\frac{1}{2}$ tons in six months. Full credit was allowed for manure dropped in the stalk fields, but manure dropped in permanent pastures was not credited to the herds. If a credit had been given, an additional charge for fertilizer would have been necessary and would have increased the pasture rent to the herd.

A ton of average manure saved on the farms studied, according to the methods used for determining it, was estimated to contain the following fertilizing constituents:

	Pounds.
Nitrogen.....	9.5
Phosphoric acid.....	2.9
Potash.....	9.8

When the nitrogen in commercial fertilizers was worth 24 cents, phosphoric acid 10 cents, and potash $11\frac{1}{2}$ cents a pound, the fertilizing value of these ingredients in a ton of manure would have been \$3.70.

REQUIREMENTS FOR KEEPING A BULL.

On most of the farms the bulls were allowed to run with the cows both in summer and in winter. As shown in Table 5, the bulls received very little grain.

TABLE 5.—Requirements for keeping a bull, by seasons, based on averages obtained from the equivalent of 29.5 bulls.

Item.	Winter.	Summer.	Entire year.
Feed:			
Purchased concentrates.....pounds..	25	10	35
Home-grown grain.....do.....	644	144	788
Total concentrates.....	669	154	823
Noncommercial roughage.....pounds..	501	386	887
Commercial carbohydrate hay.....do.....	266	75	341
Commercial legume hay.....do.....	1,757	764	2,521
Total dry roughage.....do.....	2,524	1,225	3,749
Succulent roughage.....pounds..	2,185	841	3,026
Bedding.....do.....	129	6	135
Pasture.....	\$2.98	\$17.41	\$20.39
Human labor.....hours..	10.5	5.6	16.1
Horse labor.....do.....		.3	.3
Other costs:			
Interest on bull investment.....	\$6.30	\$6.34	\$12.64
Bull's share of buildings.....	6.07	6.11	12.18
Depreciation on bull.....	12.77	12.86	25.63
Total other costs.....	\$25.14	\$25.31	\$50.45

During the second year one of the bulls died and five were sold for beef at prices far below their purebred values. These facts account largely for the depreciation of \$25.63 per bull per year.

FACTORS INVOLVED IN THE PRODUCTION OF MILK.

FEED.

Concentrates, in the meaning of this study, are grains and their by-products prepared for feeding.

Home-grown grains are concentrates grown on the farm or in the locality where fed.

Dry roughage includes various hays and other bulky feeds. Dry roughage is subdivided into the three following classes:

Noncommercial dry roughage applies to coarse feeds, such as corn stover and velvet-grass hay, for which price quotations are not given

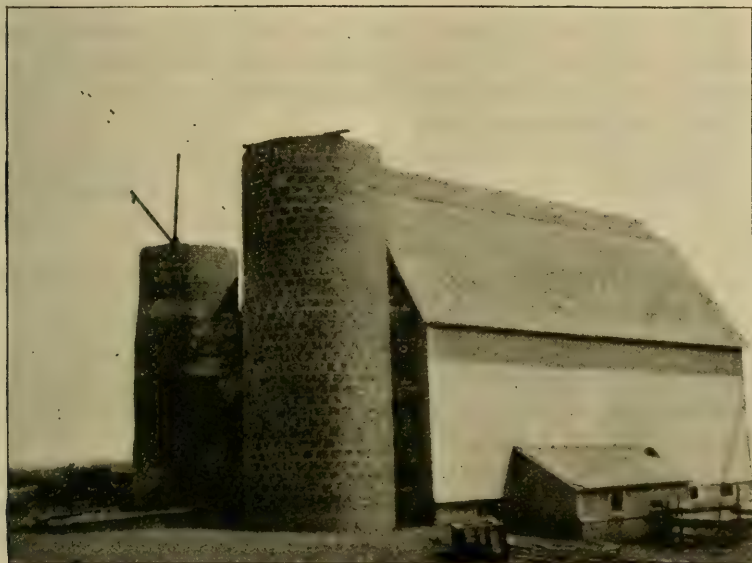


FIG 2.—Barn and silos on one of the farms studied.

in the trade papers. Hay or other dry roughage so foul with weeds or so damaged in curing as not to be readily salable is also classified under this heading.

Commercial legume hay includes alfalfa, clover, cowpea, soy-bean, and other marketable legume hays, when pure, or when so slightly mixed with grasses as not materially to affect the protein content.

Commercial carbohydrate hay refers to all marketable hays except those classified as legume hay.

Succulent roughage consists of mangels, potatoes, silage, and soiling crops.

The quantities of the various feeds used were obtained from actual weights made by the field agent on his regular monthly visit to each farm.

Purchased concentrates were charged at the prices paid. The home-grown grains were given the farm price, plus extra charges for hauling and grinding, when necessary. The value of silage was based upon the value of the grain and roughage in it, less the difference between the cost of harvesting the corn and the cost of putting it into the silo.

PASTURE.

The rent on permanent pasture was obtained by adding the interest and taxes on the land and the upkeep and repairs on fences. Where meadows or stalk fields were pastured, the rent was based upon the prevailing rate in the section, or upon a fair rent based upon the quantity of feed obtained from the field. The rather common practice of allowing the stock to roam at will over fields after the crops had been harvested made it impracticable to express the pasture charge on an acreage basis.

In normal years pastures usually are poor from the last of July until September. During the war the high price of grain tempted many of the farmers to plow up pasture land and sow it to grain, so that the acreage in pastures was greatly reduced.

Sweet clover furnishes good pasture in this section. On one farm 20 acres were sowed to sweet clover, with oats as a nurse crop. The oats yielded 32 bushels an acre, and 15 head of cattle and 8 horses were pastured for two months after the oats were cut. The following summer the sweet-clover pasture carried 18 head of cattle and 8 horses from May to September, inclusive.

On another farm $13\frac{1}{2}$ acres of sweet-clover pasture carried 21 cows, 6 calves, and 4 horses from June 1 to September 15. The grazing could have begun a month earlier with beneficial results to the pasture, as the plants were too large and coarse by June 1.

LABOR.

Grain growing is the principal type of farming in this section, and on many farms in summer the herds were cared for and milked late, after the men had done a hard day's work in the fields. Table 6 shows that in summer nearly four-fifths of the work about the dairy was performed by the manager or by the family help. In winter nearly three-fourths of it was performed by the manager with the help of his family.

In all items involving a charge for labor, expressed in dollars and cents, the cost of management has not been included. When the manager worked, his time was charged up at the same price that he would have had to pay if he had hired a man of equal skill to take his place. The reason for not making a definite charge for management is because no satisfactory basis has been found upon which to make this charge.

TABLE 6.—Percentage of labor performed and hours per 100 pounds of milk by each class of help.

Class of labor.	Winter.				Summer.			
	Distribution of work performed.			Labor per 100 pounds of milk.	Distribution of work performed.			Labor per 100 pounds of milk.
	1917-18	1919-20	Average.		1918	1920	Average.	
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Hours.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Hours.</i>
Managers.....	50.9	59.1	54.3	1.07	52.3	49.4	51.1	0.98
Hired men.....	26.7	26.1	26.4	.52	17.9	25.8	21.1	.41
Total man labor.....	77.6	85.2	80.7	1.59	70.2	75.2	72.2	1.39
Women.....	12.1	14.1	12.9	.26	14.	20.6	16.8	.32
Boys and girls.....	10.3	.7	6.4	.13	15.6	4.2	11.0	.21
Total human labor.....	100.0	100.0	100.0	1.98	100.0	100.0	100.0	1.92

As is seen in Table 7, work connected with the dairy is divided into three groups—production, handling, and hauling to the shipping platform. Production includes feeding, milking, and the general care of the herd. Handling comprises such items as washing the utensils, cooling the milk, and getting it ready for hauling. On one farm hauling to the market was done by the owner himself; on the others it was done by a motor truck which called at the dairies and picked up the milk which had been hauled short distances to the road on the route of the truck. The item of hauling in Table 7 does not include the time taken by the motor trucks, as it was paid for in cash.

TABLE 7.—Human labor used in producing, handling, and hauling 100 pounds of milk to the shipping platform.

Kind of work.	Winter.				Two winters.				Summer.				Two summers.	
	1917-18		1919-20						1918		1920			
	<i>Hours.</i>	<i>Per ct.</i>	<i>Hours.</i>	<i>Per ct.</i>	<i>Hours.</i>	<i>Per ct.</i>	<i>Hours.</i>	<i>Per ct.</i>	<i>Hours.</i>	<i>Per ct.</i>	<i>Hours.</i>	<i>Per ct.</i>	<i>Hours.</i>	<i>Per ct.</i>
Production.....	1.89	92.3	1.71	90.8	1.81	91.7	1.93	96.3	1.41	88.2	1.67	87.1		
Handling.....	.13	6.3	.13	6.9	.13	6.6	.27	12.3	.15	9.2	.21	11.0		
Hauling.....	.03	1.4	.04	2.3	.04	1.7	.03	1.4	.04	2.6	.04	1.9		
Total....	2.05	100.0	1.88	100.0	1.98	100.0	2.23	100.0	1.60	100.0	1.92	100.0		

OTHER COSTS.

Under the heading of "other costs" are grouped miscellaneous costs, such as interest, taxes, insurance, and depreciation, on the herd, buildings, and equipment, also the cost of keeping the bull, and similar items.

BUILDINGS.

The investment in buildings, including silos, averaged \$85.16 per cow per year. The depreciation per year was based upon their remaining years of usefulness. Insurance charges were taken from

the premium receipts of the insurance companies. The cost for upkeep and repairs was obtained by keeping an actual record of expenditures during the year. The footing of the first column of Table 8 shows that the total of the costs against buildings amounted to 13.8 per cent of the capital invested in buildings, and the other totals show corresponding percentage relationships.

TABLE 8.—*Per cent relationship between "other costs" and capital invested.*

Item.	Buildings.	Equip- ment.	Herd.	Total.
Capital invested.....	\$421, 127. 96	\$9, 805. 62	\$66, 501. 50	\$118, 435. 08
Capital invested per cow.....	85. 16	19. 82	134. 43	239. 41
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Interest.....	6. 0	5. 9	5. 9	
Depreciation.....	3. 4	15. 2	3. 6	
Taxes.....	. 7		. 6	
Insurance.....	. 4		. 3	
Upkeep and repairs.....	3. 3	. 9		
Milking-machine repairs.....		. 9		
Total.....	13. 8	22. 9	10. 4	12. 6

EQUIPMENT.

A monthly record of repairs and renewals of equipment was made. The amounts spent for dairy supplies were also recorded month by month and amounted to \$1.12 per cow per year.

HERD.

The cows had an average inventory value of \$134.43. Purebred cows were inventoried at fair prices for grade animals of similar producing ability, and the calves dropped by the purebred cows were inventoried at corresponding grade values. Inventories were taken at the beginning and end of each year. The value of cows which entered the herd during the year was added to the first inventory, and the receipts for cows or hides sold during the year were added to the second inventory before determining the depreciation or increase in value of the herd for the year.

The feed, labor, and "other costs" of keeping the herd sires were kept separate, so they would be available for study. Interest was charged at 6 per cent, the prevailing rate in the section. Records were kept of the actual amounts of money spent during the year for veterinary services, medicines, and disinfectants. These expenditures amounted to 60 cents per cow per year.

PERCENTAGE COMPARISON OF FACTORS INVOLVED IN MILK PRODUCTION.

How much more did it cost to produce milk in winter than in summer? What caused the variation in cost? Did the credit for calves and manure and the debit for "other costs" balance each other? Table 9 answers these questions.

TABLE 9.—Percentage of the total costs represented by feed, labor, and other costs, by seasons.

Cost item.	Winter.	Summer.	Entire year.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Feed and bedding.....	33.4	10.9	44.3
Pasture.....	1.7	10.0	11.7
Feed, bedding, and pasture cost.....	35.1	20.9	56.0
Labor.....	8.9	7.9	16.8
Other costs except herd inventory variation.....	12.3	12.3	24.6
Total cost except herd inventory variation.....	56.3	41.1	97.4
Depreciation on herd.....	1.3	1.3	2.6
Total cost of production.....	57.6	42.4	100.0
Credits:			
Calves.....	3.6	2.6	6.2
Manure.....	6.9	.5	7.4
Total credits.....	10.5	3.1	13.6

The first two columns of Table 9 show that the difference of 15.2 per cent in the cost of producing milk in winter and in summer was due principally to the difference in cost of the feed, bedding, and pasture.

The high prices received for cows sold tended to reduce the depreciation charge. The depreciation charge is reported separately, so that the amount and its effect on the total cost can be seen.

AVERAGE COMPARED WITH BULK-LINE COSTS.

During the last few years attempts have been made to use the average cost of production as a basis for determining the selling price of milk. Where the average cost basis is recommended it is evident that practically all those producers whose costs are above the average will find their profits small even if they are so fortunate as not to suffer an actual loss. This will tend to discourage production and reduce the available supply.

It is to be expected that the cost of producing 100 pounds of milk will vary in different dairies and in the same dairy from season to season. The varying costs per 100 pounds of milk have been tabulated in ascending order in Table 10.

In the scale of costs there is a line below which the greater quantity of the milk is produced. This is known as the bulk line. The determination of the limits of the bulk-line cost depends in part upon the supply needed. However, it is usually set at some point which includes from 80 to 90 per cent of the total supply. An examination of the second, fourth, and fifth columns of each season in Table 10 shows one or more points where the bulk line could be located. It will be noted that during the winter of 1919-20, 82.5 per cent of the milk was produced at a cost of \$3.45 or less per hundred. At \$3.51 or less 86.7 per cent of the total supply of milk was produced. Thus 4.2 per cent more milk was obtained at an increased cost of 6 cents per hundred. Then there was a sharp

advance to \$3.85 in the cost of production with only a small quantity of milk, 6.5 per cent, produced. If the price of milk is based on the cost of production, one should ask whether 6.5 per cent more milk is worth an increase of 34 cents (\$3.85 minus \$3.51) per 100 pounds. In this range of costs one logical location for the bulk line is at \$3.51, since this figure includes 86.7 per cent of the total quantity of milk produced. It is not logical to locate the bulk line at \$3.85, since there is an increase of 34 cents in cost and only 6.5 per cent additional milk supplied. When all the present supply is needed, the supply will be maintained if the price for milk is sufficiently above the bulk-line cost to encourage increased production by the low-cost producers.

TABLE 10.—*Net cost, quantity, and percentage of milk produced by each herd during two winters and two summers.*

Winter, 1917-18.					Winter, 1919-20.				
Herd No.	Cost per 100 pounds.	Milk produced.			Herd No.	Cost per 100 pounds.	Milk produced.		
		Quantity.	Proportion of total.	Cumulative proportion.			Quantity.	Proportion of total.	Cumulative proportion.
423	\$2.01	10,490	1.2	1.2	433	\$2.21	40,301	6.4	6.4
402	2.02	187,691	22.5	23.7	426	2.27	35,839	5.7	12.1
417	2.08	64,061	7.6	31.3	425	2.59	15,754	2.5	14.6
421	2.51	26,600	3.2	34.5	431	2.60	37,052	5.9	20.5
420	2.62	30,424	3.6	38.1	417	2.69	57,972	9.3	29.8
	¹ 2.73				432	2.70	35,891	5.7	35.5
415	2.79	44,843	5.4	43.5	427	2.78	41,388	6.6	42.1
410	2.85	59,013	7.0	50.5	420	3.04	33,790	5.4	47.5
	² 2.86				434	3.10	65,751	10.5	58.0
404	2.88	19,201	2.3	52.8	403	3.15	18,913	3.0	61.0
403	2.94	14,181	1.7	54.5		² 3.18			
408	2.98	72,048	8.6	63.1	404	3.21	9,181	1.5	62.5
418	3.01	30,814	3.7	66.8	428	3.41	36,639	5.9	68.4
409	3.07	26,004	3.1	69.9	429	3.45	87,840	14.1	82.5
416	3.19	27,425	3.3	73.2		¹ 3.47			
407	3.26	23,658	2.8	76.0	409	3.51	25,990	4.2	86.7
411	3.41	22,706	2.7	78.7	416	3.85	40,428	6.5	93.2
406	3.58	33,617	4.0	82.7	405	4.39	19,083	3.1	96.3
413	3.64	27,045	3.2	85.9	410	6.96	23,362	3.7	100.0
412	3.78	49,084	5.9	91.8					
405	4.12	23,741	2.8	94.6					
419	4.28	32,655	3.9	98.5					
422	4.62	9,937	1.5	100.0					
Summer, 1918.					Summer, 1920.				
423	\$1.15	29,663	4.1	4.1	427	\$1.62	48,401	6.9	6.9
403	1.50	37,931	5.2	9.3	429	1.76	75,467	10.8	17.7
421	1.80	35,688	4.9	14.2	404	1.77	27,932	4.0	21.7
416	2.13	40,062	5.5	19.7	425	1.80	37,494	5.4	27.1
410	2.24	40,671	5.6	25.3	416	1.83	55,053	7.9	35.0
415	2.26	32,944	4.6	29.9	420	1.91	40,468	5.8	40.8
408	2.41	72,138	10.0	39.9	434	2.20	87,176	12.5	53.3
407	2.43	30,531	4.2	44.1	403	2.26	26,907	3.9	57.2
404	2.45	21,366	3.0	47.1		² 2.38			
	¹ 2.59				426	2.47	29,098	4.2	61.4
409	2.66	22,520	3.1	50.2	417	2.69	56,058	8.0	69.4
	² 2.74					¹ 2.70			
406	2.88	26,539	3.7	53.9	433	2.80	45,057	6.4	75.8
411	2.90	19,335	2.7	56.6	409	2.90	29,688	4.3	80.1
417	3.02	49,170	6.8	63.4	432	2.95	28,937	4.1	84.2
402	3.18	59,736	8.3	71.7	431	3.26	24,335	3.5	87.7
422	3.35	12,975	1.8	73.5	410	3.38	25,568	3.7	91.4
412	3.36	59,565	8.2	81.7	428	3.52	40,744	5.8	97.2
420	3.37	26,434	3.7	85.4	405	3.95	19,814	2.8	100.0
418	3.50	30,042	4.2	89.6					
419	3.78	33,636	4.7	94.3					
413	4.16	18,509	2.6	96.9					
405	4.35	22,456	3.1	100.0					

¹ Average income from milk.

² Average cost.

MONTHLY DISTRIBUTION OF FACTORS IN MILK PRODUCTION.

During the last few years many dairymen have requested an analysis of the cost of producing milk on a monthly basis. Such an analysis is given in Table 11.

TABLE 11.—*Distribution, by months, of milk prices, milk produced, feed cost, and labor required.*

Month and season.	Income per 100 pounds of milk.	Income from milk sold and used.	Milk, sold and used.	Feed, pasture, and bedding cost.	Feed, pasture, and bedding cost minus manure and bedding credit.	Human labor.		Horse labor.	
						Per 100 pounds of milk.	Per cow.	Per 100 pounds of milk.	Per cow.
1917-18.		<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Hours.</i>	<i>Hours.</i>	<i>Hours.</i>	<i>Hours.</i>
May.....	\$2.39	9.2	10.2	6.8	6.7	2.0	11.3	0.138	0.79
June.....	2.31	8.1	9.4	6.0	5.9	2.1	11.2	.041	.23
July.....	2.43	7.4	8.2	6.3	6.1	2.4	11.6	.056	.27
August.....	2.64	6.9	6.9	5.6	5.5	2.5	10.1	.313	1.28
September.....	2.88	6.8	6.3	7.5	7.4	2.3	8.7	.137	.52
October.....	3.27	6.6	5.4	5.9	5.7	2.4	8.9	.090	.34
Summer.....	2.59	45.0	46.4	38.1	37.4	2.2	10.4	.124	.58
November.....	2.78	7.7	7.4	7.8	5.9	2.1	9.1	.034	.15
December.....	2.87	8.7	8.0	10.8	8.9	2.2	12.3	.034	.16
January.....	2.80	9.7	9.2	12.1	10.1	2.1	11.3	.025	.13
February.....	2.80	9.0	8.6	11.1	9.1	2.1	10.3	.026	.13
March.....	2.72	10.4	10.2	11.3	9.4	1.9	10.8	.034	.19
April.....	2.48	9.5	10.2	8.8	6.8	1.9	10.0	.051	.27
Winter.....	2.73	55.0	53.6	61.9	50.1	2.1	10.3	.034	.17
Year.....	2.67	100.0	100.0	100.0	87.5	2.15	10.35	.079	.375
1919-20.									
May.....	2.87	9.6	10.3	7.2	7.0	1.5	8.6	.04	.21
June.....	2.31	8.6	11.4	7.3	7.1	1.4	9.1	.01	.09
July.....	2.40	7.9	10.2	5.8	5.6	1.4	7.9	.02	.11
August.....	2.62	6.9	8.1	4.7	4.5	1.7	7.3	.02	.10
September.....	2.89	6.7	7.1	4.6	4.4	1.8	7.2	.02	.08
October.....	3.58	6.7	5.7	7.1	6.9	2.2	7.7	.11	.40
Summer.....	2.70	46.4	52.8	36.7	35.5	1.6	8.0	.03	.15
November.....	3.69	7.1	5.9	8.2	6.0	2.1	7.7	.11	.39
December.....	3.74	8.7	7.1	12.1	9.9	1.9	8.4	.10	.47
January.....	3.59	9.9	8.4	12.3	10.0	2.0	10.6	.19	.98
February.....	3.43	9.2	8.2	12.2	10.0	2.0	9.5	.09	.43
March.....	3.36	9.6	8.8	10.0	7.8	1.8	9.5	.06	.31
April.....	3.15	9.1	8.8	8.5	6.3	1.5	7.8	.08	.39
Winter.....	3.47	53.6	47.2	63.3	50.0	1.9	8.9	.10	.49
Year.....	3.06	100.0	100.0	100.0	85.5	1.75	8.45	.065	.32

The third column of Table 11 shows the percentage of the yearly income from milk which was obtained each month. The percentage of the yearly quantity of milk produced each month is found in the fourth column. The fifth column shows the monthly feed, pasture, and bedding cost to produce milk, and the sixth shows the same costs after the credit for manure and bedding has been deducted. The remaining columns show the amounts of labor expended for producing 100 pounds of milk, and also for keeping a cow.

SUMMARY.

The requirements for producing 100 pounds of milk were obtained from records covering two one-year periods with an interval of one year between them. During the winter six months these requirements were: Concentrates, 41.2 pounds; hauling and grinding concentrates, \$0.016; dry roughage, 95.3 pounds; silage and other

succulent roughage, 93.6 pounds; pasture, \$0.108; bedding, 11.1 pounds; human labor, 2 hours; horse labor, 0.06 hour; total other costs except depreciation on cows, \$0.788; depreciation on cows, \$0.081. During the summer six months there were required: Concentrates, 11 pounds; hauling and grinding concentrates, \$0.004; dry roughage, 51.2 pounds; silage and other succulent roughage, 29.3 pounds; pasture, \$0.653; bedding, 0.5 pound; human labor, 1.9 hours; horse labor, 0.08 hour; total other costs except depreciation on cows, \$0.805; depreciation on cows, \$0.084. (Table 1.)

The requirements for keeping a cow one year were: Concentrates, 1,529 pounds; hauling and grinding concentrates, \$0.60; dry roughage, 4,275 pounds; silage and other succulent roughage, 3,593 pounds; pasture, \$22.01; bedding, 340 pounds; human labor, 113.6 hours; horse labor, 3.2 hours; total other costs except depreciation on cows, \$46.35; depreciation on cows \$4.78. (Table 2.)

There was a credit, per year, of 0.93 of 1 calf for each cow, which amounted to 0.03 of 1 calf for each 100 pounds of milk produced. (Table 3.) The credit for manure per cow per year amounted to 7,749 pounds, and for 100 pounds of milk it amounted to 264 pounds. (Table 4.) It was estimated that a ton of this manure contained 9.5 pounds of nitrogen, 2.9 pounds of phosphoric acid, and 9.8 pounds of potash. (Page 8.)

In the winter season 54.3 per cent of the work was performed by the manager, 26.4 per cent by the hired men, 12.9 per cent by women, and 6.4 per cent by boys and girls. During the summer 51.1 per cent was performed by the manager, 21.1 per cent by hired men, 16.8 per cent by women, and 11 per cent by boys and girls. (Table 6.)

The building costs for the year were 13.8 per cent of the capital invested in them, the equipment costs were 22.9 per cent of the capital invested in equipment, and herd charges were 10.4 per cent of the capital invested in the herd. The combined cost of buildings, equipment, and herd was 12.6 per cent of the total capital invested in them. (Table 8.)

Fifty-six per cent of the cost of milk was due to feed, bedding, and pasture, 16.8 per cent to labor, 2.6 per cent to depreciation on cows, and 24.6 per cent to other costs. There was a credit of 6.2 per cent for calves and 7.4 per cent for manure. (Table 9.)

The average incomes from milk during the first winter and summer were not sufficient to meet the average costs during those seasons. In the second year the incomes were above the average costs in both seasons. (Table 10.)

The greater percentage of the year's income was received in the winter, but the feed, pasture, and bedding costs were heavier at this time and exceeded the summer costs by a greater percentage than the winter receipts exceeded the summer receipts. (Table 11.)

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MILK-PLANT OPERATION.

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THE NEED FOR TECHNICAL KNOWLEDGE.

The successful operation of a milk plant requires, besides general ability, considerable technical knowledge and training. New milk plants are constantly being established, especially by organizations of producers or of producers and small dealers, and the question of management is of considerable importance. The success of new milk plants usually depends to a large degree on the manager; and capable managers are often difficult to find. Sometimes men can be obtained who have the proper personality and general business ability but lack the technical knowledge for successfully managing a milk plant. The purpose of this bulletin is to give such men, as well as men who are already in the business, information regarding methods used in operating milk plants successfully.

The construction, arrangement, and equipment of milk plants have been considered in previous publications issued by the Department of Agriculture.¹ Certain information regarding operation was also included in these publications. This bulletin describes briefly the various operations in somewhat the same order as they occur in the ordinary city milk plant.

¹ U. S. Department of Agriculture Bulletin No. 849, "City Milk Plants, Construction and Arrangement," and U. S. Department of Agriculture Bulletin No. 890, "Milk-Plant Equipment."

RECEIVING MILK AT THE PLANT.

The milk as received from producers, directly or through country cooling plants, is usually brought to the plant in trucks, either from the railroad station or directly from the country. These trucks are unloaded at the receiving platform; the milk is graded and dumped, and the cans are washed and returned to the trucks, so that they can go back to the producer to be filled again with milk.

All milk should be received at the plant in the morning, if possible. It is usually desirable to have it all in before noon, so as to avoid hauling during the heat of the day, and so that the work of receiving at the plant may be completed in good season each day.

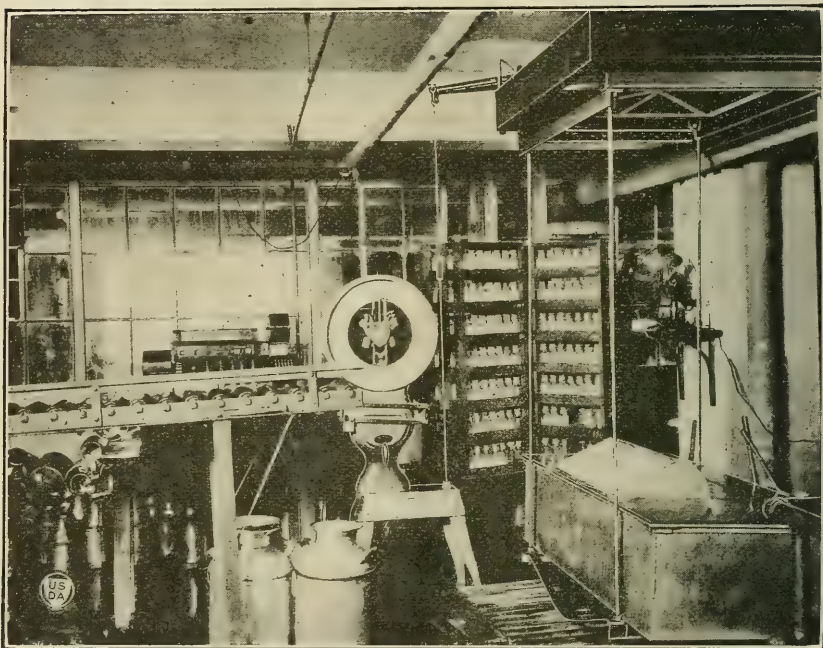


FIG. 1.—Portion of receiving room, showing scales of overhead-lever type, weigh can, conveyer on which cans are conveyed to wash room, and fan to blow flies away from the milk.

The milk-plant manager is responsible for the quality of the milk put out at the plant, and he must therefore direct that the milk is properly cared for at the farm where it is produced. One of the most important points in this connection is that of keeping the milk cool. Producers should be instructed to use ice early in the spring to cool the milk. Usually more sour milk is received at the plant in the spring and fall than during the summer, because producers fail to realize the importance of cooling at these times, and do not begin to use ice early enough nor continue its use late enough.

The manager can help to have the milk arrive at the plant in good condition by having it brought to the plant immediately on arrival at the railroad station, and when it reaches the plant it should be sent immediately to the pasteurizer or kept in a cool place until it is pasteurized. No milk should be allowed to remain in a warm receiving room.

In large cities there is a wide variation in the age of the milk received at the plants. Figures obtained from the principal dealers in five cities on the age of the milk when received showed variations of from 2 to 48 hours, a large proportion being from 12 to 24 hours old.

The milk-plant manager should arrange to have the milk reach the plant as fresh as possible. He is, of course, dependent on train schedules. At some small plants near the source of production it may be advisable to receive the milk twice a day, as it can be kept cold at the plant more easily than at the farm.

GRADING, SAMPLING, AND TESTING.

Milk should be dumped and weighed as soon as received. Each can of milk must be examined to determine its condition. (Fig. 2.)



FIG. 2.—Inspection of milk on arrival at plant.

This may be done by smelling or tasting, and milk with objectionable flavors or odors should, of course, be rejected. Fingers or hands should never be put into milk. Spoons used for tasting should be rinsed thoroughly and sterilized after each use.

As soon as the milk is dumped into the weigh can a sample should be taken for the butterfat test. It is to the interest of both dealer and producer to have the sample properly taken and the testing properly done. (Fig. 3.) This question is of special importance, as more milk is now bought on butterfat basis than formerly. A difference between the test at the country receiving station and at the city plant indicates inaccuracy at one place or the other.

At small plants where the milk is dumped from the cans directly into the pasteurizing vat, it may be weighed in the cans. Where this is done a sample should be taken from each can, and care must be taken to mix the milk in the can thoroughly before taking the sample. Much more satisfactory results are obtained by the use of the weigh

can, because then all the milk from each producer can be mixed thoroughly and a fair sample taken. A two-compartment weigh can facilitates the weighing and sampling.²

From the time the milk is received and dumped it should be handled rapidly and should be exposed to contamination as little as possible. After the milk is weighed it usually passes through a clarifier or a filter to remove any dirt present. While large plants generally use a clarifier, very satisfactory results may be obtained with the use of a filter consisting usually of layers of cheesecloth and cotton, and considerable expense in equipment eliminated. There are also several types of mechanical filters now on the market

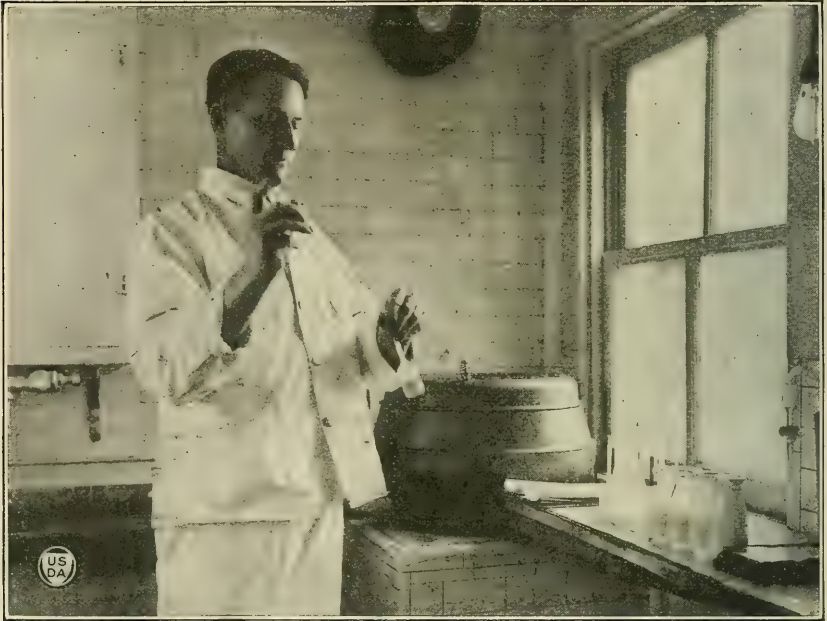


FIG. 3.—Testing milk for butterfat content.

PASTEURIZING AND COOLING.

It is important that the milk be properly pasteurized, and a competent and reliable man should be assigned to this work.

The primary purpose of pasteurization is the destruction of all pathogenic organisms in order to make the milk safe. Where milk is properly pasteurized, disease-producing organisms and nearly all other bacteria are destroyed, so that besides making the milk safe the keeping quality is improved.

In pasteurization two main objects are desired, namely, (1) destruction of all disease-producing bacteria and a reduction of the total bacterial count of the milk; (2) economy in the use of heat, power, and labor. Unless the first is accomplished the second is of little account.

² For information on testing milk, plant operators are referred to Bureau of Animal Industry Circular A-12, "Chemical Testing of Milk and Cream," which may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C., for 10 cents; stamps not accepted.

In order to pasteurize milk properly, two things are necessary:

1. The milk must be heated to 145° F. and held for 30 minutes with an accurate control of the temperature and time. After heating and holding, the milk must be immediately cooled to 50° F. or below.
2. All apparatus which comes in contact with the milk must be cleaned thoroughly and sterilized after each using.

Unless there is an automatic temperature control the steam and water valves must be carefully watched in order to maintain the proper temperature. If the milk is not heated to the proper temperature and held at that temperature, good results can not be expected. All pipes or "pockets" in which milk is held during the pasteurizing or holding process should be insulated, as otherwise the holding temperature can not be maintained. Great care must be used also that none of the valves leading from the heater or holder leak. Milk coming from the pasteurizer should never pass through any apparatus which has contained raw milk.

The cleansing and sterilizing of the apparatus is absolutely essential for good results. All milk pipes, pumps, and filler valves, as well as the pasteurizer, should be taken apart after each run, thoroughly cleaned and rinsed, and then sterilized by steam. An abundance of steam should be used. Unless all bottles and cans are thoroughly cleansed and sterilized the value of the pasteurization will be greatly reduced.

The proper pasteurization of milk is a simple operation and there is little excuse for the poor results that are obtained at some plants. Poor results are usually not the fault of the type of pasteurizer used, but of the way in which it is operated.

Following are some of the causes of poor pasteurizing results at milk plants:

- Pipes and pumps not cleaned and sterilized.
- Filler and valves not cleaned and sterilized.
- Milk rushed through the apparatus too fast.
- Milk not heated high enough nor held long enough.
- Temperature recorder not accurate.
- Bulb thermometer not accurate.
- Raw milk added to pasteurized milk in vat before the pasteurized lot is all drawn out.
- Pumps and piping not of sanitary construction.
- Leaky or inaccurate valves, which allow some of the milk to get through the apparatus without being held the proper length of time.
- Formation of foam in the holder.

Great care should be taken that valves in the pipe line do not leak. Leaky valves are a very common occurrence in many milk plants, and besides the very insanitary character of such a condition much loss of milk results from it. The prevention of milk loss is an important part of the manager's duties, and no pains should be spared to keep all valves and connections in the milk lines tight.

CONTROL OF PASTEURIZING TEMPERATURE.

One of the most important considerations in the proper pasteurization of milk is control of the temperature. In order to do this properly, an automatic device is necessary. It is difficult and often impossible to control the temperature by means of hand valves, but there are on the market automatic devices which will control the temperature very accurately.

With vat pasteurizers it is not necessary for the operator to remain constantly at the steam valve, but it is very important that the steam be shut off at the proper time. Usually the steam must be shut off just before the milk in the vat reaches 145° F. The coil may then be shut down, although some operators favor allowing the coil to revolve during the holding process in order to keep the temperature more nearly uniform and prevent the cream from rising. If the coil is run intermittently, there is much less danger of injuring the cream line than when it is run continuously. The outlet valve should not be opened to let the milk out of the vat to the cooler until 30 minutes have elapsed from the time the temperature of the milk reached 145° F., and no milk must have been added to the vat in the meantime. When continuous-flow pasteurizers are used with no temperature control, the operator must be at the steam valve constantly, and even then it is very difficult to prevent considerable fluctuation in temperature.

When an automatic device for controlling the temperature is used, it is important that the device be properly adjusted at all times.

Temperature recorders should always be used. They should be attached so as to show the temperature to which the milk has been heated. When vat pasteurizers are used the time of holding can be determined from these recorders provided the time it takes to empty the vat is known. Usually the apparatus is attached at a point near the bottom of the vat, and the record will show the total period from the time the milk first reaches the pasteurizing temperature until the vat is practically empty. The time required to empty the vat must, therefore, be deducted from the time of holding, as shown on the record chart, in order to determine the length of time all the milk was held at the pasteurizing temperature. When all or a part of the cooling is performed in the vat the record chart will show the actual time of holding at the pasteurizing temperature for the entire vat of milk.

With continuous-flow pasteurizers it is difficult to record accurately the time the milk is held at the pasteurizing temperature, and this can best be determined by means of an accurate timepiece and by means of accuracy tests.

The charts from the recording instruments are a record of how the milk has been pasteurized, and are often valuable to show health officials as well as customers how the process was performed.³

CHECKING ACCURACY OF HOLDERS.

The accuracy of all continuous-flow holders should be tested from time to time. Several different tests are used for this purpose. Automatically operated compartment holders should also be checked often to determine their accuracy. It is essential that the valve of the compartment which has been emptied should close tightly before the next lot of heated milk begins to flow in and that none of the valves leak at any time.

³ For further information on pasteurization see U. S. Department of Agriculture Bulletins No. 342, Present Status of Pasteurization, and No. 890, Milk-Plant Equipment.

COOLING.

The milk should be thoroughly cooled after heating and holding, and in order to assure this it is necessary that the cooler be of sufficient capacity. When the cooler is not large enough, care must be taken to see that the milk does not pass over it too fast, because if it does it will not be properly cooled. The milk should also be cooled with the least possible agitation.

Milk may be cooled in the vats, but in that case care should be taken not to injure the cream line; to prevent such injury the milk should be cooled quickly, with as little agitation as possible. It is more satisfactory to have a separate cooler large enough to permit quick cooling, so as to increase the capacity of the pasteurizing apparatus. Temperature recorders may be attached to the cooler in order to record the temperatures to which the milk has been cooled.

BOTTLING AND CAPPING.

As soon as the milk is pasteurized and cooled it should be put immediately into clean, sterile, cool bottles. The process of bottling and capping can be carried on at the same time as the pasteurizing process when a continuous-flow system of pasteurizing is used. The capacity of the pasteurizing outfit and the bottle filler should therefore be approximately the same, and this should be such that the work of pasteurizing and bottling in medium-sized and small plants may be done in four or five hours. Then the same set of men can be used during the remainder of the day for other work, such as receiving and weighing the milk and washing the bottles and cans. In small plants where one pasteurizing vat is used, two men can dump the milk into the vat as it is received, and as soon as it is pasteurized it may be run over the cooler, and the same two men can do the filling and capping.

The bottling should be done by machine. A machine capper also is desirable.

MAN-HOUR REQUIREMENTS FOR BOTTLING MILK BY VARIOUS METHODS.

A study was made of the labor requirements in filling and capping milk at milk plants in several of the larger cities in the United States. Figures were obtained for the labor used for the actual bottling and filling; they do not include packing of milk in the storage room after bottling. Five methods of bottling were considered:

1. The large, automatic, power fillers and cappers, which fill and cap the bottles in the case, a full case at a time. (See Fig. 4.)
2. The smaller rotary type of automatic fillers and cappers, which work automatically, but in which the bottles are taken out of the cases, and are returned to them after being filled and capped. (See Figs. 5 and 6.)
3. Automatic single-row fillers and cappers in which bottles are removed from cases and passed through the machines in rows. (See Fig. 7.)
4. Machine fillers and cappers, in which the bottles are filled and capped in the case, but the operations are accomplished by means of hand levers and not automatically.

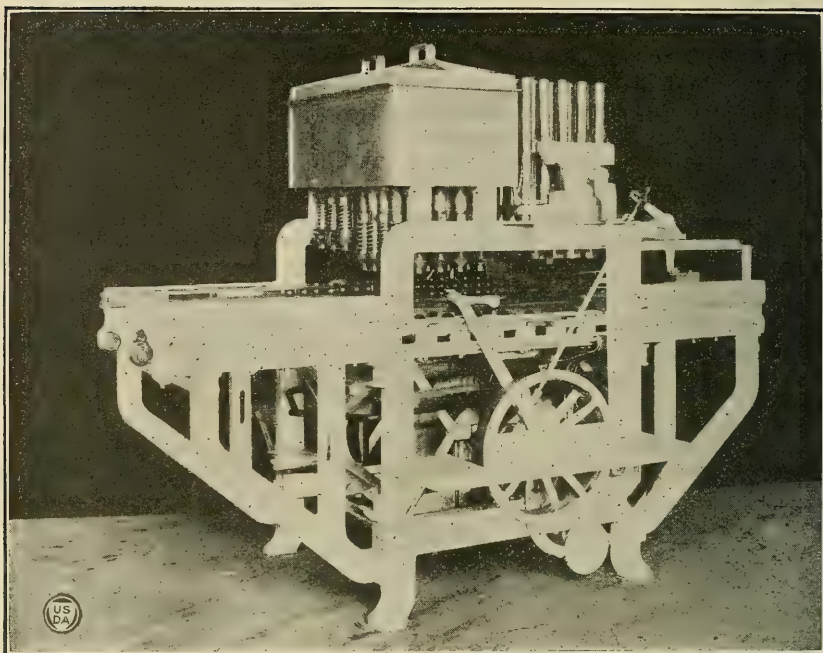


FIG. 4.—Large automatic filler and capper. A case of pints and a case of quarts can be filled simultaneously with this machine. At 15 plants using this type of machine 1,229 bottles were filled and capped per man-hour.

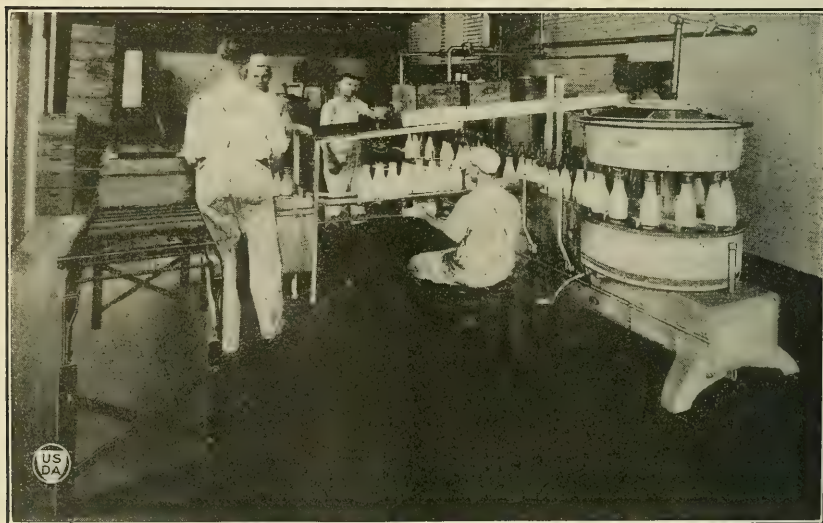


FIG. 5.—Bottling milk with automatic rotary-type machine. At 31 plants using this type of machine the average number of bottles filled and capped per man-hour was 701.

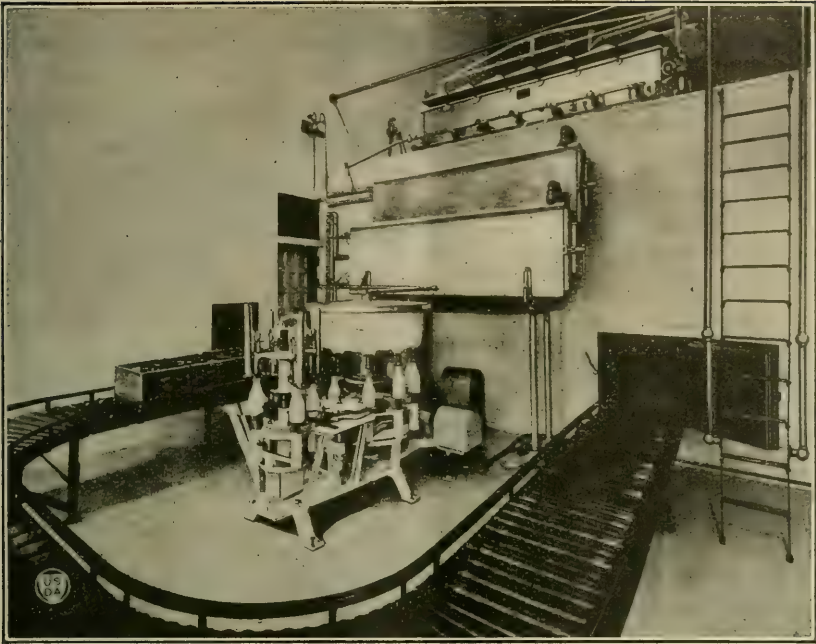


FIG. 6.—Rotary-type filler and capper. Note conveyers used to convey the bottles from the bottle-storage room and, after being filled, to the milk-storage room.

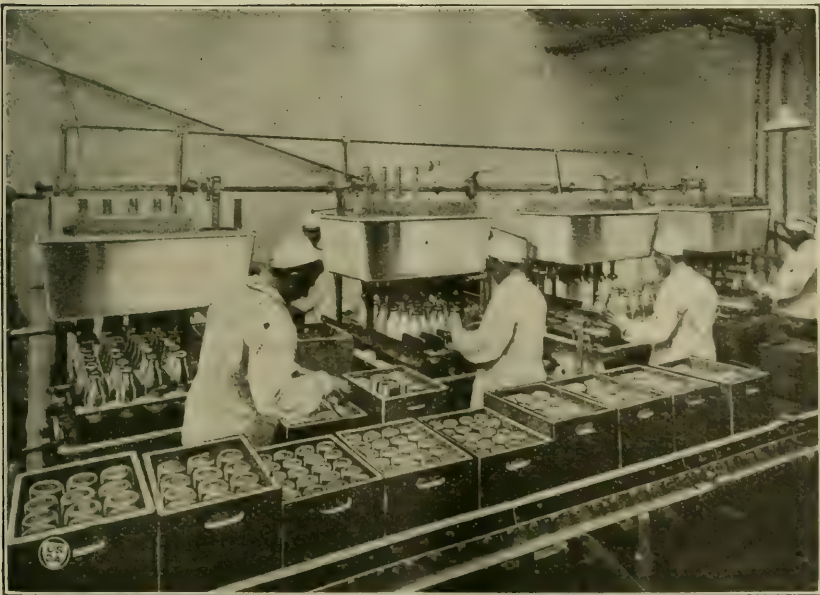


FIG. 7.—A battery of fillers and cappers of the automatic single-row type. An average of 763 bottles was filled and capped per man-hour at four plants using this type of machine.

5. Fillers in which the bottles are filled in a manner similar to the fourth method, but are capped by hand.

Table 1 shows the labor used in filling and capping with the various systems.⁴

TABLE 1.—*Comparative man-hour requirements, on the average, for filling and capping bottles with different types of machines.*¹

Type of machine.	Plants.	Cities.	Average number of machines used per plant.	Bottles filled and capped per hour.	Bottles filled and capped per man-hour.	Bottles filled and capped per machine-hour.
(1) Large automatic.....	15	5	1.50	5,994	1,229	3,895
(2) Rotary automatic.....	31	10	2.00	4,609	701	1,999
(3) Single-row automatic.....	4	4	3.75	10,136	763	2,080
(4) Machine filler and capper, operated by hand levers.....	21	8	1.50	3,717	768	2,338
(5) Machine filler, with hand capping.....	60	5	1.20	1,798	553	1,576

¹ At practically all plants where data on labor used in filling and capping and in washing bottles were obtained, the machines could be so adjusted that half-pint and gill bottles could be handled as well as quarts and pints. The data given were obtained on quart and pint bottles of milk only.

The most important items in this table are those showing the number of bottles filled and capped per man-hour. The largest number of bottles per man-hour (1,229) was filled and capped with the large automatic machine. The number filled and capped per man-hour was not greatly different with the rotary, single-row, and hand-lever types of machine, being 701, 763, and 768, respectively. The number of bottles filled and capped per machine-hour was nearly the same with the rotary and single-row types, being 1,999 and 2,080 respectively, while with the machine filler and capper of the hand-lever type 2,338 bottles were filled per machine-hour. Some of the plants using the latter type of machine had large-capacity machines, but on account of the extra men required to operate these machines there was practically no saving in labor over the other types.

In Table 2 are shown the wide variations in the man-hour and machine-hour requirements at the various plants using the various methods.

TABLE 2.—*Range of variation in the number of bottles filled and capped per hour, man-hour, and machine-hour by the different methods.*

Type of machine.	Bottles filled and capped per hour.	Bottles filled and capped per man-hour.	Bottles filled and capped per machine-hour.
(1) Large automatic.....	1,933 to 10,958	966 to 2,155	1,933 to 5,479
(2) Rotary automatic.....	1,350 to 13,333	334 to 1,437	1,114 to 3,966
(3) Single-row automatic.....	1,833 to 15,077	674 to 838	1,833 to 2,154
(4) Machine filler and capper, operated by hand levers.....	750 to 7,760	320 to 1,552	750 to 3,880
(5) Machine filler, hand capping.....	350 to 5,000	238 to 866	350 to 3,200

It can be seen in this table that there is a wide variation in the amount of work done at different plants using the same types of machinery. It will be noticed that there was a wide variation in the number of bottles filled per machine-hour, as well as in the number

⁴ For a description of various fillers and cappers, see U. S. Department of Agriculture Bulletin No. 890, Milk-Plant Equipment.

filled per man-hour. The variations in the number of bottles filled per man-hour plainly indicate differences in efficiency of operation at the various plants using similar equipment. There are several factors causing these variations, among which are:

The layout of the rooms and the arrangement of the equipment. This is the most important factor. Many plants were not conveniently arranged for handling the work; hence, extra time and men were required.

In some plants more men were used on the work than could be used economically, while in others too few men were employed to do the work to best advantage.

In the case of some types of machine a difference in capacity, without doubt, accounted for some of the variations, especially that under method No. 4.

Other factors were: Breakdown of machinery, broken bottles, cooler out of order, and waiting for milk. In this connection it is important that the capacity of the clarifier, pasteurizer, and cooler be similar to that of the bottle-filling apparatus, so that both can be operated at a uniform rate and at full capacity.

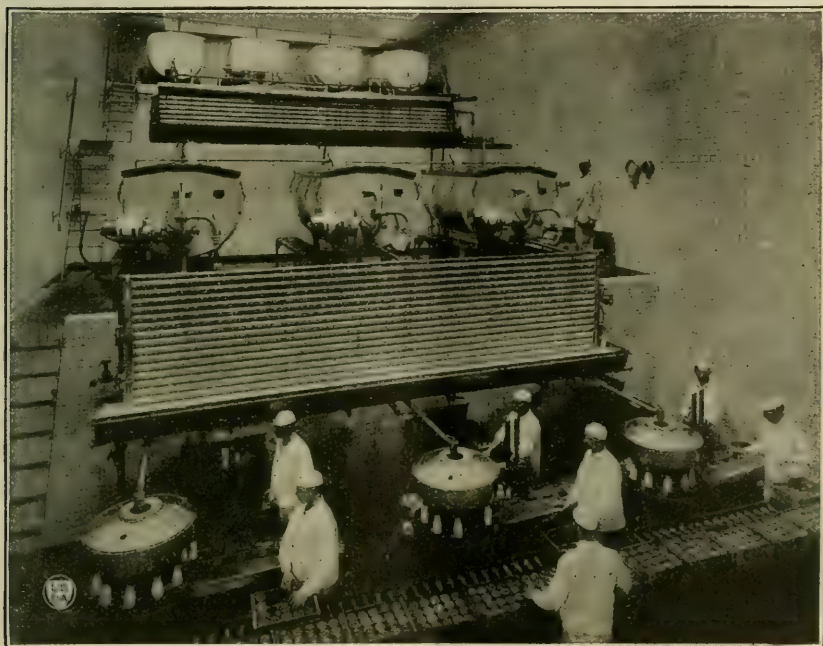


FIG. 8.—Interior view of modern milk plant, showing pasteurizers, coolers, and bottling machinery.

Among the causes of variation in the number of bottles filled per machine-hour are: Layout and arrangement of the machinery as to economy and rapidity of operation, difference in capacity of the machines in some cases, and difference in the efficiency of the labor itself.

All figures given as to number of bottles filled per hour, man-hour, and machine-hour are taken from actual conditions. They do not represent ideal conditions and do not show what the different machines can do when operated at maximum capacity under ideal conditions.

COMPARISON OF LABOR COSTS IN FILLING AND CAPPING BY VARIOUS METHODS.

In Table 3 is shown the number of bottles filled and capped per man-hour at 81 plants using the various methods and filling less than 10,000 bottles daily. Only one machine was used at each plant.

TABLE 3.—*Man-hour requirements at 81 plants bottling milk with one machine and filling less than 10,000 bottles daily.*

Type of machine.	Plants.	Average number of bottles filled and capped per man-hour.
(1) Large automatic.....	3	1,039
(2) Rotary automatic.....	13	788
(3) Single-row automatic.....	1	733
(4) Machine filler and capper, operated by hand levers.....	9	511
(5) Machine filler, hand capping.....	55	461

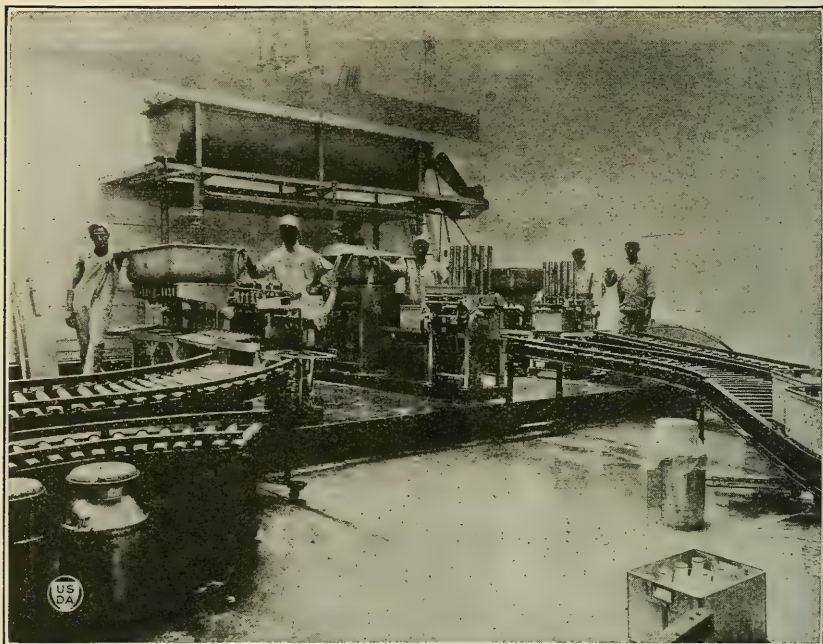


FIG. 9.—A battery of machine fillers and cappers of the hand-lever type. An average of 768 bottles was filled and capped per man-hour at 21 plants using this type of machine.

In Table 4 is shown the number of bottles filled and capped per man-hour at 45 plants filling more than 10,000 bottles daily. The average number of machines used per plant is also shown.

TABLE 4.—*Man-hour requirements for filling and capping at 45 plants filling more than 10,000 bottles daily, with average number of machines in use per plant.*

Type of machine.	Plants.	Bottles filled and capped per man hour.	Average number of machines used per plant.
(1) Large automatic.....	12	1,238	1.6
(2) Rotary automatic.....	18	691	2.7
(3) Single-row automatic.....	3	764	4.7
(4) Machine filler and capper, operated by hand levers.....	12	838	1.8

Using the data in Tables 3 and 4, it is possible to make a comparison of the labor economy of the various methods of filling and capping for plants of various sizes. The graphs, Figures 10 and 11, are based on these data. Labor in the plant was considered as costing 50 cents an hour and the allowance for depreciation and repairs on the equipment each year was considered as 20 per cent of the purchase price. The values used in the calculations for the various machines were based upon the average prices at which the particular machines used at these plants could be purchased at the time (1922).

Figure 10 shows the comparative costs for labor and for interest and depreciation on equipment for plants bottling less than 10,000 bottles daily and using only one machine. The figures used are taken from Table 3 and are based on labor costs obtained at 81 such plants. It will be noted that for this size of plant, if only one machine is used the automatic machines of the rotary and single-row types are the most economical. The higher purchase price of the large automatic machine makes its use practically prohibitive for plants of small capacities.

The costs with the machine filler and capper

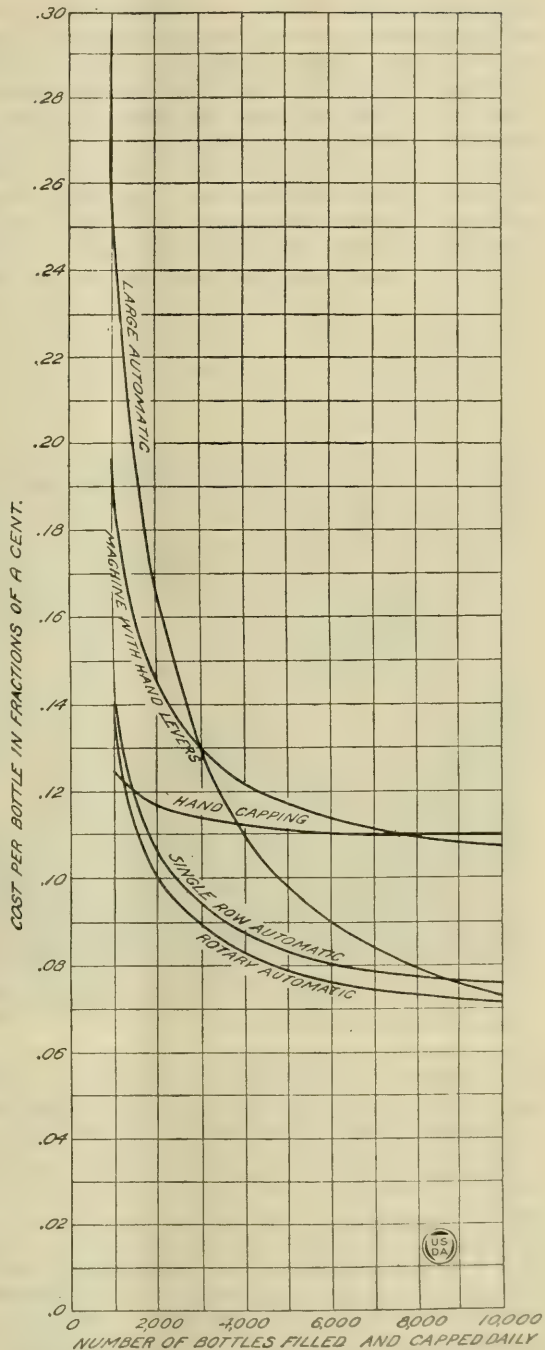


FIG. 10.—Comparative costs for labor and for interest and depreciation on equipment in five methods of bottling milk, where one machine is used, based on labor costs at 81 plants using one machine each and bottling less than 10,000 bottles daily.

operated by hand levers are consistently higher than with the rotary and single-row types of machines for all plants of this group. The costs with the large automatic machine are less than with the hand-lever machine after about 3,000 bottles are reached.

Owing to the high cost of labor, the hand-capping method is not economical for plants bottling more than 1,000 bottles daily. From a sanitary standpoint also this method is undesirable. According to the data obtained there was very little choice as regards cost of operation between the rotary and single-row types of machine. The average purchase price of the machines of these two types is practically the same, and the labor cost at the particular plants studied

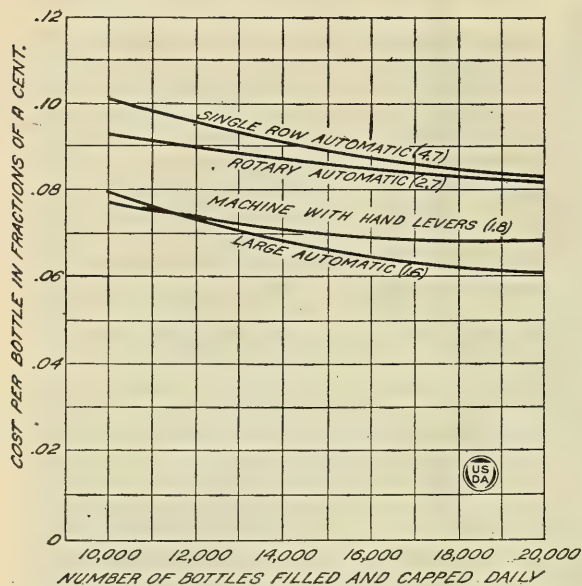


FIG. 11.—Comparative costs for labor and for interest and depreciation on equipment for four months of bottling milk for various-sized plants, computed from labor costs and the average number of machines of various types used at 45 plants bottling 10,000 bottles or more daily. Figures in parenthesis indicate average number of machines in use at each plant. The relatively higher costs with the single-row and rotary machines are due in part to the fact that in many plants some of the machines were not in constant use.

was only slightly greater with the single-row type. On account of the great variation in efficiency of labor and of plant management, and because these figures are based on only a relatively small number of plants, it would not be possible to say that one of these two types is more economical than the other.

If it should be assumed that at these plants two machines of the rotary and single-row types were used instead of one, and that the bottles filled per man-hour were the same as above, these types would still be more economical than the machine with the

hand levers for all plants in this group, while the costs with the large automatic machines would fall below those with the other two types when about 4,500 bottles are reached.

Figure 11 is based on the data in Table 4 obtained from 45 plants bottling more than 10,000 bottles daily. At these plants the average number of machines was 1.6, 2.7, 4.7, and 1.8, for the methods 1 to 4, respectively, and an allowance for interest and depreciation of 20 per cent a year is made on these numbers of machines for each method. The same values for the machines were assumed as before. Owing to the comparatively large number of machines that were used at the plants using single-row and rotary machines the costs with these machines are higher than with the other two methods, because of the larger amount that must be charged for interest and depreciation. It will be noted that at these plants the costs with the rotary and

single-row machines are approximately the same. As more machines of the single-row type than of the rotary type were used at these plants, making a greater charge for interest and depreciation, the costs with the former are slightly greater. In the case of the machine with hand levers and the automatic case-filling machine, the cost per bottle with the latter becomes comparatively less as the size of the plant increases.

At first glance the curves in Figure 11 seem to indicate that the costs of using the single-row and rotary machines were considerably higher than at plants using the large automatic and hand-lever types. In part, however, this is due to the fact that many of the plants using the former types had some machines which were not in constant use. In some cases an extra machine had been installed to take care of emergencies, such as breakdowns. This is a wise precaution against having the work come to a standstill, but the high cost of the large automatic types operates to prevent having extra large machines.

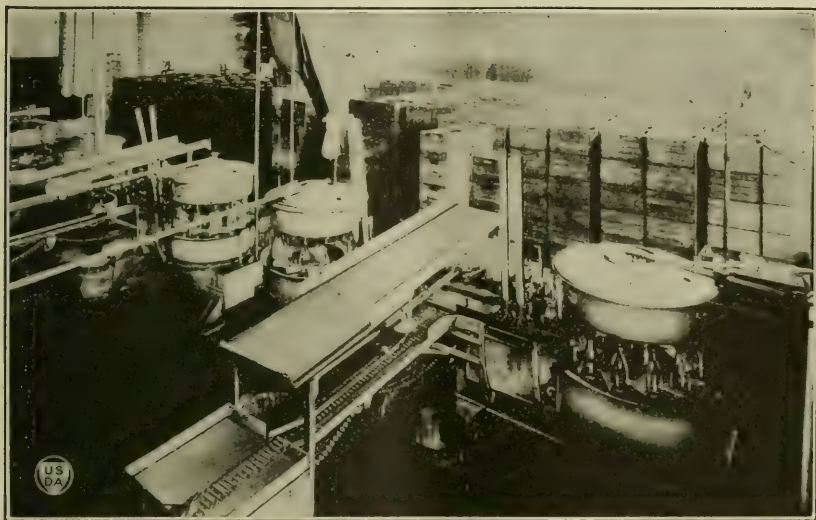


FIG. 12.—A battery of rotary automatic fillers and cappers, with special conveyer system which reduced the number of men required to operate the machines.

The difference in actual cost at these plants between the rotary and single-row machines on the one hand and the hand-lever and large automatic machines on the other, is not great, and other factors are involved which have resulted in the more general use of the rotary and single-row types. Among the advantages of the latter types are:

The smaller machines are more convenient because they are more adapted to be used in units. If one machine breaks down the work will not have to stop, as the other machines can be operated while the broken one is being repaired. As the business increases, additional units can be readily added.

Inspection of bottles can be much more readily carried on with these types of machines, as the bottles are removed from the cases in the operation.

The machines are automatic and the results are not wholly dependent on the men.

As compared with the automatic machines that are used for filling bottles while in the cases ("case-filling machines"), there is less mechanism to get out of order and the operation is much more simple with the smaller types of machine.

WASHING BOTTLES.

The milk bottles should be washed in ample time to be thoroughly cool before they are filled with milk. If the bottles are not cool, the temperature of the milk put into them is raised. This means a waste of refrigeration, and an increased development of bacteria is possible. At many plants bottles are washed in the morning and filled in the afternoon. Great care should be taken to see that the bottle washer is always in working order, for if the bottles are not properly cleaned and sterilized the pasteurization of the milk may be of little value.

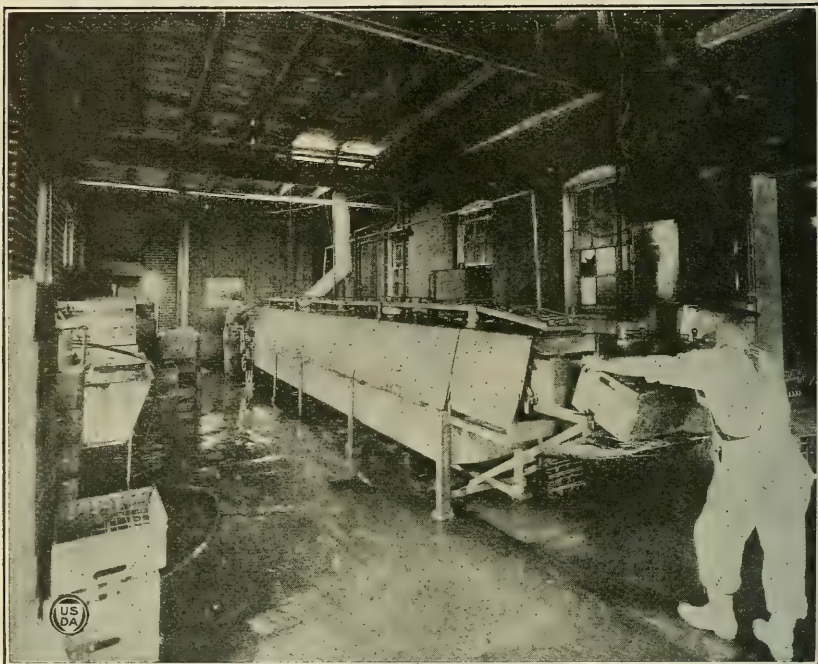


FIG. 13.—Automatic bottle washer. An average of 1,002 bottles per man-hour was washed at 56 plants using machines of this type.

In case a brush washer⁵ is used, the brushes should be changed before they become worn, and the washing water should be changed often during the day. Great care must be taken to see that the rinsing and steaming device of the machine is in good working order at all times. Each bottle should receive a strong jet of rinsing water and then a jet of steam for at least 45 seconds. Jet openings should be free from obstructions. After the bottles are washed they should be kept in a cool, clean place until wanted for filling. If the bottles are inverted in the cases, there is less chance for contamination. It is a good plan to use special cases at the washer and transfer the bottles, after they are washed and steamed, to clean, dry cases. If the same cases that are used in the washer are used also to store the bottles, there will be a constant drip from each case into the case below, and these cases also soon become soggy. If

⁵ For a description of types of bottle washers see U. S. Department of Agriculture Bulletin No. 890, "Milk-Plant Equipment."

this course is followed, the empty bottles should be inverted in the cases so as to avoid the drip from the next case above.

At medium-sized or large plants automatic pressure washers are commonly used. (See Fig. 13.) These machines also give the cases a washing and steaming which keeps them in good condition. Where these automatic washers are used care must be taken to see that all the jet openings are working at all times and that the solutions in the various tanks are kept at the proper strengths and temperatures. The temperature in the first tank should not be above 100° or 120° F. at the highest, so that the bottles will not be broken. Each succeeding tank should be a little hotter until the final tank, which should be near the boiling point.

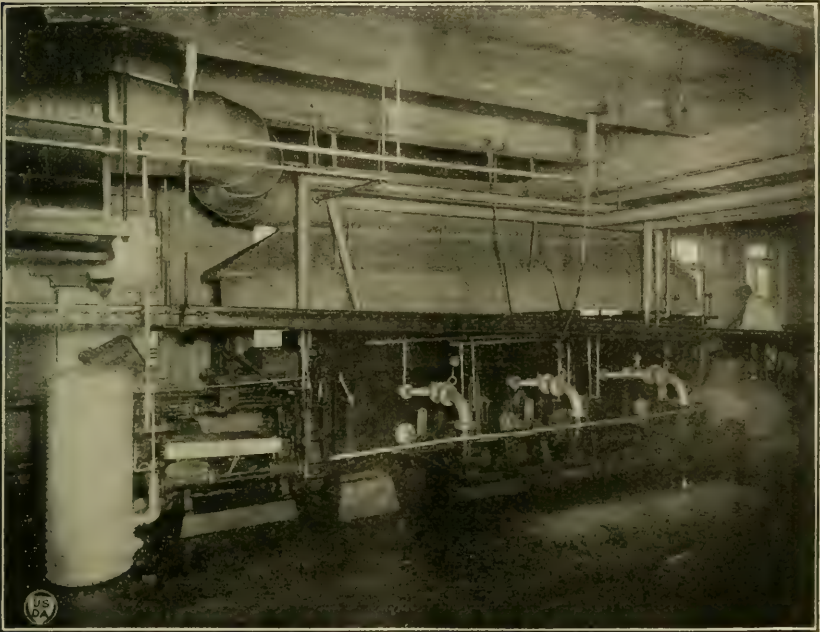


FIG. 14.—Automatic bottle washer showing pumps; thermometers indicate the temperatures in the various tanks.

In small machines of this type with only two or three tanks, the increase in temperature of the water in the various tanks is more sudden. Table 5 gives temperatures observed in the various tanks at several plants. (See Fig. 14.)

TABLE 5.—Temperatures observed in the various tanks of automatic-pressure washers at several plants.

Plant No.	Number of tanks.	Temperatures of the various solutions in tanks.				
		Tank 1.	Tank 2.	Tank 3.	Tank 4.	Tank 5.
		°F.	°F.	°F.	°F.	°F.
1.....	5	120	140	160	180	200
2.....	4	90	120	160	200	.....
3.....	4	100	120	140	170	.....
4.....	3	110	150	180	.....	.....
5.....	3	90	140	180	.....	.....

MAN-HOUR REQUIREMENTS FOR WASHING BOTTLES.

A study of the labor required for washing bottles was made in different cities at plants using various types of machines. In Table 6 are given the man-hours of labor used in washing bottles at various plants, arranged according to the number of bottles washed daily. Two types of bottle washers are considered:

1. The automatic-pressure washer, which consists of a series of tanks containing washing solutions and rinsing waters, which are forced into the bottles through jets by powerful pumps.

2. The ordinary brush washer, which consists of a mechanically driven brush, with tanks in which the bottles are soaked and rinsed, and a chamber for steaming the bottles.

In the column showing "number of bottles washed per man-hour" it will be noted that for the plants using automatic washers the number of bottles washed per man-hour tends to increase, and the number of man-hours required to wash 1,000 bottles tends to decrease with the size of the plant. The group of plants washing from 20,000 to 40,000 bottles daily is an exception to the general tendency, because one plant in this group used an exceptionally large amount of labor, thus making the average labor cost for the whole group considerably greater than it would be if this plant were eliminated. This particular plant had an arrangement that was very expensive (as to number of men required) for transferring bottles from the wash rooms to the clean-bottle storage room and thence to the filling room. The bottles, too, were transferred to another set of cases before going to the washer, thus requiring considerable extra labor. Sixteen men were used at this plant in the bottle-washing department, while the average for the group is only 4.6 men.

TABLE 6.—Hours of labor employed for washing bottles at plants of various sizes, using various methods.

Number of bottles washed daily.	Plants.	Average number of bottles washed per plant.	Average number of men per plant.	Average number of man-hours per plant.	Number of bottles washed per hour.		Number of bottles washed per man-hour.		Number of man-hours used per 1,000 bottles washed.	
					Average.	Variation.	Average.	Variation.	Average.	Variation.
Automatic washers (1 machine):										
10,000 or less.....	19	6,079	2.7	6.0	2,497	1,296 to 5,400	1,004	648 to 1,691	1.00	0.59 to 1.54
10,001 to 20,000.....	12	16,146	3.6	15.6	3,622	2,523 to 5,000	1,036	780 to 2,169	.96	.46 to 1.28
20,001 to 40,000.....	17	28,811	4.6	31.2	4,278	2,760 to 7,916	920	281 ¹ to 2,209	1.10	.46 to 1.35
40,001 to 60,000.....	5	51,587	6.2	48.4	6,614	4,666 to 10,187	1,066	694 to 1,718	.94	.58 to 1.44
Over 60,000.....	3	79,333	8.0	72.0	8,815	7,556 to 11,111	1,102	855 to 2,519	.91	.40 to 1.17
Average for 56 plants.....	23	125	4.0	23.1	4,628	1,296 to 11,111	1,002	281 to 2,519	1.05	.40 to 3.55
Automatic washers (2 machines):										
50,000 to 90,000..	4	63,500	13.2	110.0	7,582	5,555 to 10,588	577	375 to 844	1.73	1.19 to 2.66
Turbine brush washers:										
1,000 or less.....	10	626	1.6	2.1	447	250 to 780	305	250 to 400	3.28	2.5 to 4.0
1,001 to 2,000.....	17	1,503	2.4	4.2	710	233 to 1,700	360	233 to 566	2.77	1.8 to 4.3
2,001 to 3,000..	9	2,321	2.4	7.3	685	430 to 1,150	317	215 to 525	3.16	1.9 to 4.6
3,001 to 5,000....	7	3,943	3.1	11.0	952	400 to 2,400	358	250 to 525	2.79	1.9 to 3.7
Above 5,000.....	6	8,700	5.0	29.3	1,582	1,000 to 3,200	297	200 to 800	3.37	1.2 to 5.0
Average for 49 plants.....	2	704	2.6	8.4	928	233 to 3,200	323	200 to 800	3.0	1.2 to 5.0 ²

¹ One plant in this group used an exceptionally large number of men for this work.

² Total range of variation.

In the case of the plants using the brush washer there is no definite relation between man-hours used and the size of the plant. It will be seen in the columns "Number of bottles washed per man-hour" and "Number of man-hours used per 1,000 bottles washed" that there is no regular increase or decrease in those figures with the size of the plants. At small plants using the brush washers the men are usually shifted from one kind of work to another and the work of bottle washing is not so well systematized as is the case at larger plants. At the plants using the automatic machinery the larger plants are able to economize on labor. On account of the large volume of work of a similar nature that has to be done, such plants naturally use special efforts to eliminate all labor not essential, and use special men for each type of work.

One of the outstanding points illustrated by the data in Table 6 is the large variation in the quantities of labor required at the various plants of similar size using the same type of equipment. For example, at 12 plants washing from 10,000 to 20,000 bottles daily with automatic washers, the number of bottles washed per man-hour varies from 780 to 2,169. Apparently the less efficient plants in this group could reduce their labor costs by adopting the methods used at the more efficient plants. The most obvious cause of such variations seems to be the arrangement of the various plants. Many plants are very inconveniently arranged, so that extra men are required to transfer the bottles from place to place, and in many instances some of these men could be eliminated by a rearrangement of the rooms and equipment in the plant.

It will be noted in the table that at plants washing more than 5,000 bottles daily with brush washers the work is done even less economically than at the smaller plants. The average number of bottles washed per man-hour at the larger plants is only 297, while the average for all plants using brush washers is 323. From a study of the figures in Table 6 it seems evident that such plants could operate more economically if they would install automatic bottle washers. In the group of plants washing 10,000 bottles or less daily with automatic machines, an average of only 1 man-hour is required per 1,000 bottles washed; while in the group of plants using brush washers, an average of 3 man-hours is required to wash 1,000 bottles.

Table 7 shows the average numbers of bottles washed per hour and per man-hour at 111 plants, using the methods (1) automatic machine, (2) brush washer, and (3) swabbing out with a hand brush. The variations in the man-hour requirements with the various methods are also shown.

TABLE 7.—*Hours of labor (average) used in washing bottles, also variations in number of bottles washed per hour, man-hour, and machine-hour, at 111 plants using the different methods.*

Method of washing.	Automatic machine.	Brush washer.	Hand washing.
Number of plants.....	56	49	8
Number of cities.....	15	10	3
Bottles washed per hour.....	4,628	928	433
Variation.....	1,296 to 11,111	233 to 3,200	180 to 950
Variation in number of bottles washed per machine-hour.....	1,296 to 7,916	233 to 2,400	.....
Bottles washed per man-hour.....	1,002	323	199
Variation.....	281 to 2,519	200 to 800	135 to 266
Man-hours used per 1,000 bottles washed.....	1	3	5

A wide variation in efficiency is also shown where the same method of washing is used. There are many factors that cause these variations, as, for example, some of the machines of the same type are more serviceable and of a larger capacity than others; also, the operators are delayed from time to time by numerous unavoidable causes, such as breakdowns, broken bottles, or lack of steam, but the greatest factor in causing these variations is the arrangement of the plant. The management and handling of labor are also important factors.

COMPARISON OF COSTS IN WASHING BOTTLES.

Using the data in Table 7 as to number of bottles washed per man-hour, it is possible to make a comparison of costs in washing bottles by the various methods for plants of various sizes. According to this table the average number of bottles washed per man-hour at 56 plants using one automatic washer each was 1,002; at 49 plants using brush washers, 323; and at 8 plants washing with a hand brush, 199. Assuming that labor is worth 50 cents an hour, which is about the average at these plants at the present time (1922), the labor cost per 100 bottles washed would be 4.99 cents, 15.48 cents, and 25.13 cents for the three methods respectively. The capacity of the automatic washer used at the various plants varied considerably, of course, but a fair estimate of the present average purchase price of the automatic machines used at all the plants is \$3,500.⁶ For the brush washer the average current price (1922) for the particular types used would be about \$400. Assuming that the depreciation and other annual expense on the bottle washers is 20 per cent of their purchase price, this charge would amount to \$1.92 a day for the automatic machine, and \$0.22 a day for the brush washer. In the case of hand washing this extra charge would not be worth considering. Using these averages for labor cost and for interest and depreciation on the machines, Figure 15 was worked out to show the relative costs for labor and interest and depreciation on the equipment of the various methods for plants washing different numbers of bottles daily. The cost per bottle is shown in the left-hand margin, while the number of bottles to be washed is shown in the bottom margin.

Hand washing is represented by a straight line, as the labor cost would be the same per bottle, regardless of the number washed, and no charge for interest and depreciation is considered. The line showing the cost with the brush washer crosses that representing the cost with the automatic machine at about 1,600 bottles, indicating that when this or any larger number of bottles is to be washed it would be advisable to consider the economy of installing an automatic washer. The high wages that have to be paid for labor in the plant have an important bearing on this question. The hand-washing system is out of the question for any plant at present prices (1922) of labor and the brush washer is economical only at very small plants.

A similar graph was worked out to represent conditions in 1914 previous to the present high prices for labor and equipment. This is shown in Figure 16. The labor costs used were the average for 40 plants using automatic washers, 43 plants using brush washers, and 8 plants where the bottles were washed by hand. The average number

⁶ Such plants should also have a brush washer to take care of the very dirty bottles. Such a brush would add slightly to the total cost.

of bottles washed per man-hour was 1,044, 342, and 199 for the three methods, respectively. These numbers were not greatly different from those given in Table 7, upon which the costs in Figure 15 were based. The cost of labor at the plants where the data were obtained was approximately 20 cents an hour in 1914. At that time the average purchase price of the machines used in the plants was approxi-

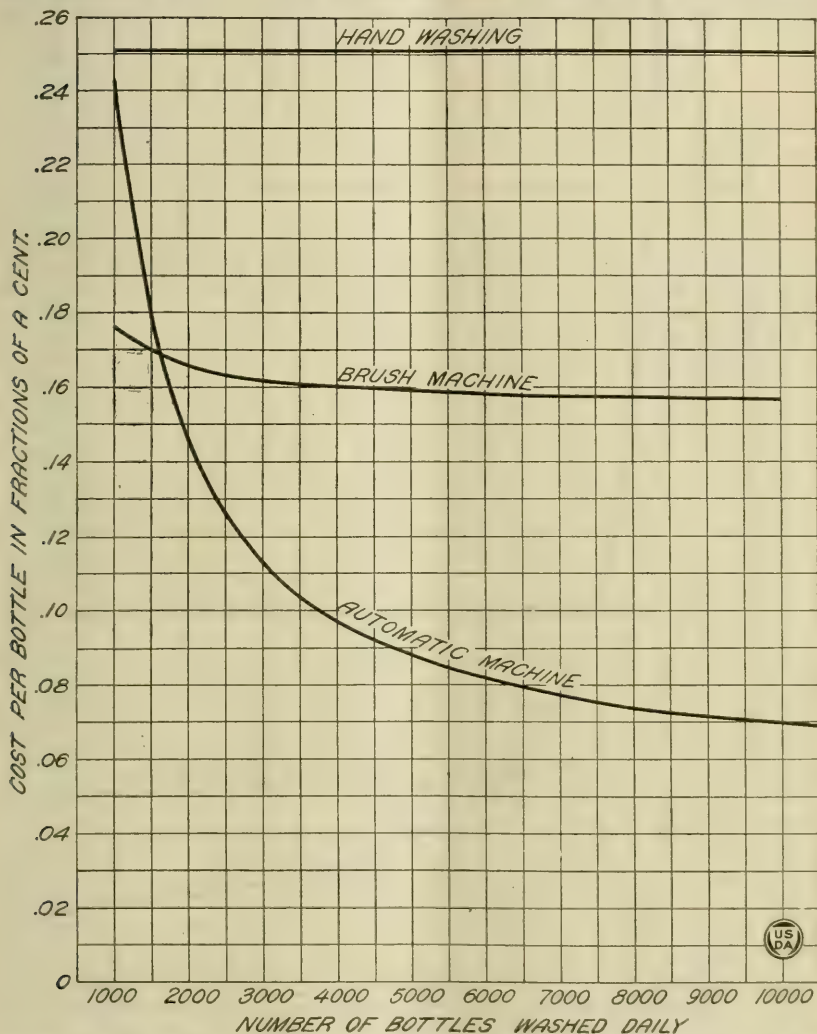


FIG. 15.—Comparative costs for labor and for interest and depreciation on equipment with three methods of washing bottles, based on labor requirements at 113 plants. (Prices of 1921.)

mately \$1,500 for the automatic machines and \$175 for the brush washers. The lines representing the automatic and the brush-washing types intersect at about 2,300 bottles, indicating that when this number of bottles was reached it would have paid a dealer to consider the economy of changing from an ordinary brush washer to the automatic machine.

By comparing Figures 15 and 16 it is apparent that even though equipment is much more expensive now (1922) than in 1914, the

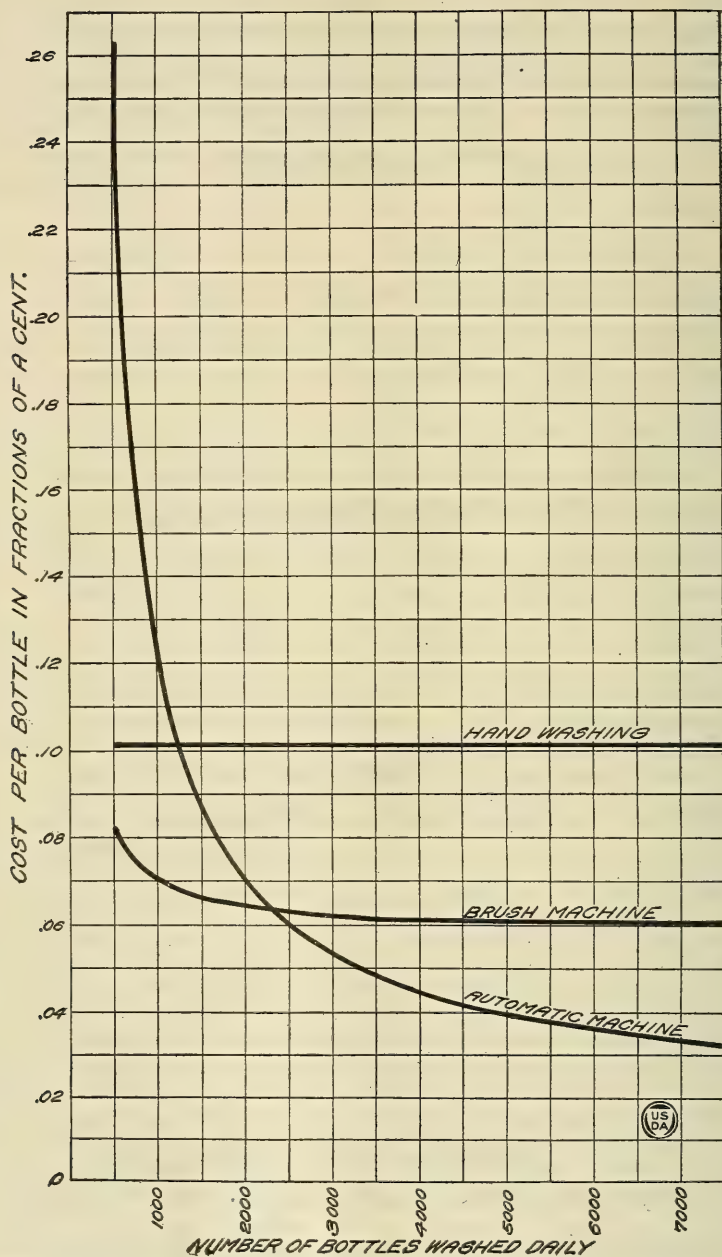


FIG. 16.—Comparative costs for labor and for interest and depreciation on equipment in washing bottles by different methods at plants of various sizes, based on labor costs at 91 plants and prices for 1914. The cost of both labor and machinery has greatly increased since these figures were obtained; the figures are useful, however, to show the comparative costs with the different methods used.

economy of using machinery is even more obvious than at that time, owing to the fact that the cost of labor is so much higher than it was in 1914. According to Figure 16, hand washing was more economical than the automatic machine for plants washing less than 1,200 bottles daily, while the brush washer was more economical than the automatic machine for plants washing up to about 2,300 bottles daily. According to Figure 15 hand washing is not economical for plants even of the smallest size, and the brush washer is economical only for plants washing 1,600 bottles or less.

In the illustrations it can be seen that in order to determine the relative economy of the various methods of washing bottles the cost of the machine and of labor in the particular locality must be carefully considered. The variation in the efficiency of different men must be taken into account also.

Another factor to be considered in determining which type is the most economical is the time required to wash a given number of bottles. Time in the milk plant is an important factor, and methods of operation must be followed that will provide for the work being accomplished in a definite time. It will be noted that at 56 plants using automatic washers the average number of bottles washed per hour was 4,628, while at 49 plants using brush washers the average number of bottles washed was only 928. Thus if a plant has, let us say, 5,000 bottles to wash it will take, according to these figures, more than five hours with a brush washer, while the work could be done with an automatic machine in a little more than an hour. It is generally desirable at medium-sized or small plants that the bottle washing take no more than half of the day, so that the men doing this work can be employed elsewhere during the remainder of the day. For example, one set of men may wash the bottles in the morning and bottle milk in the afternoon. In that case the bottle washing must be done in from three to four hours. It is therefore necessary at such plants to select a bottle washer which will permit the work to be done in this time, and as a general rule it is to the advantage of the dealers handling this number of bottles to use the automatic rather than the brush washer. Where only one or two men are washing bottles and they are not suitable to help in filling bottles, it may be economy to keep them washing bottles for the greater part of the day; in that case a brush washer would be satisfactory, provided they could wash all the bottles with it in from six to eight hours. In any case, however, thoroughness is of first importance, and such methods should be used as will result in the most thorough cleansing and sterilization.

In the discussion of labor costs in bottling milk and in washing bottles, no attempt has been made to include all types of machinery. The studies made include the more common types in use, although other more recent types are on the market.

INSPECTION OF BOTTLES.

While the large automatic pressure washers give satisfactory results in general, there are always some bottles that will not be thoroughly cleaned. Bottles that have stood for several days, or those in which the casein of the milk has dried, will pass through the machines without being properly cleaned. It is necessary that all such bottles be culled out and washed with a hand brush before they are sent through

the automatic washer. It is a good plan to soak these very dirty bottles overnight in a solution of washing powder. To take care of such bottles it is advisable to have a small brush washer (without rinsing apparatus) besides the automatic pressure washer.

Besides culling out dirty bottles before they enter the machine, it is necessary that the bottles be inspected after they leave the machine. (See Fig. 17.) Milk delivered in a dirty bottle often means the loss of a customer, besides being objectionable from a public-health standpoint. In large plants inspectors are often so placed that the bottles are inspected as they leave the bottle washer, again before they are filled, and finally after being filled with milk; and even then it is possible for some dirty bottles to get out to the trade. Some dealers

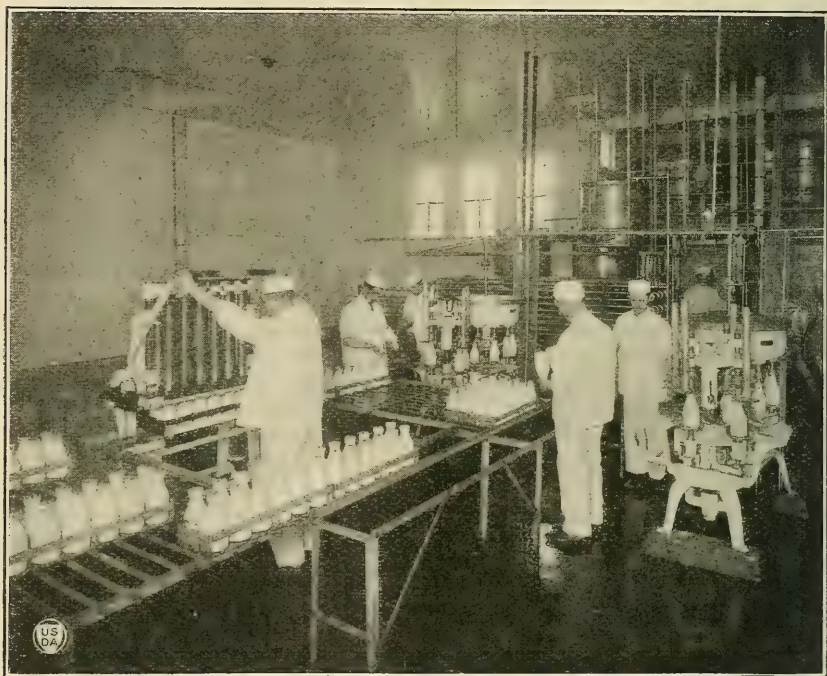


FIG. 17.—Filling and capping bottles by machinery. Note inspection of bottles both before and after filling.

have considered the advisability of washing all bottles on a brush washer before they go to the automatic machine, in order that all dirty ones will be thoroughly cleaned. As a rule this would cause needless extra expense, since even with this method an inspection system would be required. After the bottle is filled with milk the dirt often shows much more plainly than before filling it, making it important that the bottle be inspected after it is filled.

At one plant a rather unique and satisfactory method of bottle inspection was used. The inspector at the bottle washer was held responsible for all dirty bottles that he let go through to the filling room. He was paid on a commission basis, as was also the inspector at the fillers. For all dirty bottles found by the inspector at the filling machine he was paid a certain premium and the commission of

the inspector at the bottle washer was reduced a similar amount. In this way the men took a special interest to prevent bottles from passing without careful inspection.

As it is very important that the bottles be thoroughly cool before the milk is put into them, and as they must be kept clean while cooling, a separate room for storing clean bottles should be provided in the plant, unless there is a bottle-cooling arrangement between the bottle washer and the fillers.⁷

WASHING CANS.

The matter of washing cans, while only a small part of the daily operations, is a very important one. Many different methods are used at various plants in caring for the cans after the milk is removed from them. There are a number of different types of cleaning machines on the market. The aim of the efficient ones, however, is thorough cleansing with washing powder and water, followed by rinsing, sterilization with steam, and rapid drying. After this the can should be covered and kept from contamination. Some of the largest machines are fitted with powerful pumps, and as the cans in an inverted position are run through the machine, sprays of washing powder and water, rinse water, hot water, and steam successively are forced into them under considerable pressure. They are then dried in the same machine by a blast of hot air.

Very satisfactory results can be obtained at small plants by washing the cans thoroughly with a hand brush and water to which washing powder has been added. The cans should then be rinsed and steamed with a jet of live steam for at least 45 seconds. After steaming, the cans should be allowed to stand for a few seconds until thoroughly dry. Covers should then be placed on them. It is important that the cans be well dried, and if they are subjected to sufficient steaming they will become dry in a few seconds. Not only does drying leave the can in a better condition as to cleanliness, but it tends to prevent rust and prolong the life of the can. The cover should be thoroughly washed and steamed before being returned to the can.

SANITATION IN CITY MILK PLANTS.

The importance of cleanliness in the handling of milk can not be overestimated. In order to put out a high quality of milk, both cleanliness and care in handling are required. On arrival at the plant, the milk should either be put in a cold place or immediately started on its course through the plant. The cans of milk may either be put into the refrigerator or have ice packed around them, or the milk may be stored in tanks provided for the purpose. These tanks should be in a cold room or insulated with a jacket, so that the milk may be kept at a low temperature until it is put through the plant. The milk should be strained or put through a clarifier or a filter which removes the greater portion of insoluble dirt in the milk. At small plants satisfactory results can be obtained from the use of a simple strainer or filter of cheesecloth and cotton. Some sort of rack or holder is necessary to support the filter; the cheesecloth is first laid on one of these holders and then some sterilized cotton is placed on

⁷ See U. S. Department of Agriculture Bulletin No. 849, "City Milk Plants—Construction and Arrangement."

it and the cheesecloth folded over it. Another rack is then placed over the whole. The filter is then attached either to the dumping device or to the receiving tank. It will be necessary usually to change the filter during the day (depending on the quantity of milk handled), as the cotton will become filled with dirt; also, if care is not taken, the cotton may get out of place so that some of the milk will pass through without going through the cotton. The cheesecloth must be thoroughly washed and sterilized after each use, and kept in a clean place. It can be used several times before it is thrown away. The cotton should be thrown away after it is used once. The milk should pass through the various pieces of apparatus with as little exposure to the air as possible; and after pasteurization, cooling, and bottling it should be kept in the cold-storage room until taken

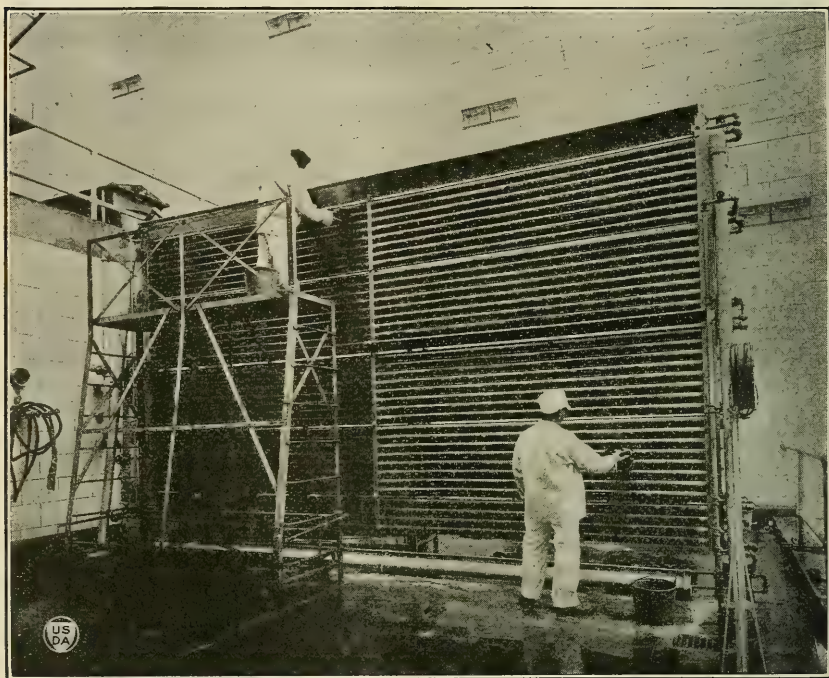


FIG. 18.—Cleaning a milk cooler in a large plant. It is later steamed.

to the delivery wagons. It is very essential that the milk be cooled to 50° F. or below and held there until delivered to the consumer.

As soon as the milk is put up, all parts of the apparatus should be cleaned thoroughly by first rinsing in cool or tepid water, then washing with hot water to which washing powder has been added, and finally sterilizing with boiling water or steam. (See Fig. 18.) After the milk has passed through the apparatus it is a good plan to pump cool water through the entire system first, and then hot water to which washing powder has been added. The pumps and pipes can be rinsed by pumping water through them immediately after using. They should then be taken down and thoroughly washed, which can easily be done if there are frequent hand couplings in the pipes. After washing and rinsing the pumps and pipes they should be steril-

ized with steam. The cleaning and sterilization of the milk piping and pumps are often neglected. While it is sometimes possible to clean the pipes satisfactorily by means of pumping solutions through them, followed by thorough rinsing and steaming, usually this is not sufficient. It is much more satisfactory to take down and clean the piping thoroughly every day. At many plants complaints are received about the quality of the milk, that it turns sour quickly, etc., and the operator is often at a loss to know what the trouble is, as he has been careful with the temperatures used in pasteurization and the milk is kept cold after pasteurization. Often the trouble is found to be with the milk pipes, joints, and pumps. If the pipes are not thoroughly cleaned and sterilized each day, filth and dirt will soon collect at joints and elsewhere, and the milk passing through

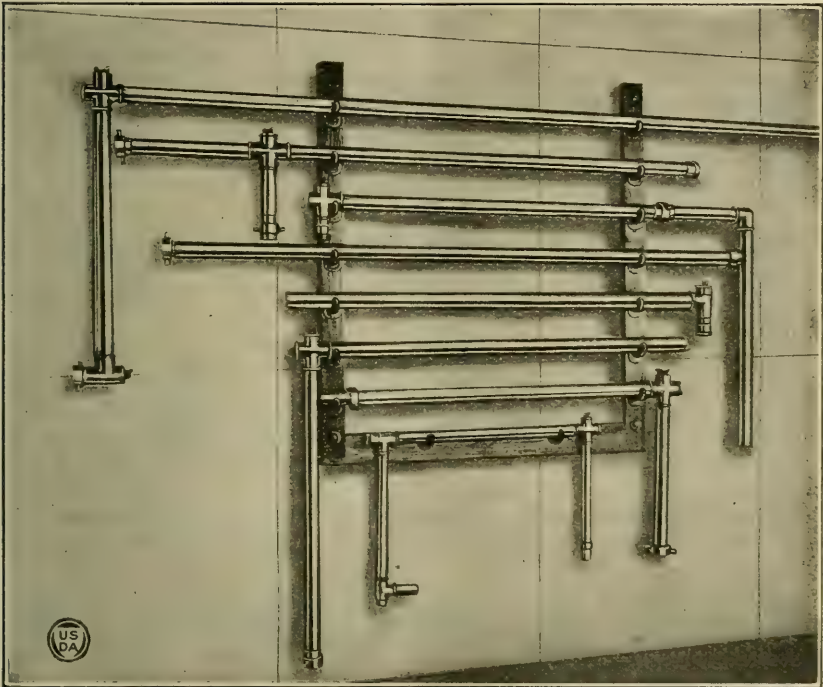


Fig. 19.—Milk piping after being disconnected, washed, and steamed.

such apparatus will be badly contaminated and will be of very poor quality.

Great care should be taken in cleaning the pasteurizing outfit. This should be rinsed immediately after using, and then thoroughly cleaned and finally rinsed and steamed. Small brushes must be used to get at the parts of this apparatus and no effort should be spared in keeping the pasteurizer clean. After the work with the milk has been finished, water should be run through the apparatus, followed by water to which washing powder has been added, and a thorough cleaning with brush, then rinsing and steaming.

Much attention should be paid to keeping flies out during the warm season. All windows and doors should be well screened. Revolving fans placed near and blowing toward the door, which should open

outward, will often greatly assist in reducing the number of flies that enter the building. These fans provide a constant breeze, which forces many of the flies out as the doors are opened. Fans placed near milk apparatus, such as open coolers, also tend to keep flies away from the apparatus and out of the milk. Good ventilation is essential. (See Department Bulletin No. 849, "City Milk Plants.")

Keeping a milk plant clean is a simple matter if one bears in mind the fundamentals of sanitation and has a fair idea of bacteriological principles. Everything with which the milk comes in contact should be kept clean from a bacteriological standpoint—that is, thoroughly sterilized with steam. Milk should be exposed to the air as little as possible; it should be pasteurized at 145° F. for 30 minutes and then kept at 50° F. or below until delivered.

The delivery outfit is another item that should receive attention in respect to cleanliness. Many dealers naturally take great pride in the cleanliness of their plant. The delivery outfits should not be forgotten, for customers have an opportunity to see them every day, while only a few ever visit the plants. The horses should be kept in good condition and well groomed, the harnesses clean and well oiled, and wagons well painted and washed. Drivers should be clean, neatly dressed, courteous, and obliging. Many a good customer has been lost by a discourteous driver, while many a new one has been gained by a polite and obliging one. A uniform or a white suit adds much to his appearance. Where cash sales are made in office buildings or other places in which the customer deals directly with the driver this is especially desirable.

WASTES INCURRED IN HANDLING MILK.

One of the aims of the milk-plant operator is to keep the losses in the plant as low as possible. These losses vary considerably at different plants, depending mostly on the competence of the men in charge.

There are many items which should be borne in mind by the milk-plant operator in keeping down losses. The following items are important:

- Avoid milk piping as much as possible by the proper arrangement of rooms and equipment. Not only is the piping difficult to keep clean, but it causes extra labor. Besides, considerable milk will stick to the pipes at the end of the run, and extra piping will increase the loss of milk.

- Avoid use of milk pumps wherever possible by use of the gravity-flow system. Extra labor is required for cleaning pumps, and the gravity system is more sanitary.

- Keep a close watch for leaks, spillage, slop, etc., in the milk handling, so as to keep the shrinkage as low as possible.

- Drain cans well after dumping the milk.

- Have milk vats set so that they can be readily drained.

- Keep all joints in milk pipes tight to avoid leaks.

- Utilize all milk returned by drivers, and drain the containers after dumping.

- Shut down motors or other machinery as soon as through using them, and thus avoid power waste.

- Avoid extra shafting, pulleys, etc.

- Avoid extra steam piping by proper arrangement of rooms, and thus avoid losses due to condensation of steam.

- Keep steam valves and joints well packed to avoid leakage.

- Keep all machinery well oiled, but avoid waste of oil by careful use and by catching the drip.

- Avoid water wastes. Save water from cooler coils and from condenser coils whenever possible. Too much water used in washing also requires extra washing powder. Water hose should not be left running when not needed.

Utilize exhaust steam whenever possible to heat water for use in the plant; also to heat boiler-feed water, and to heat the building.

Avoid waste of ice. Leaving ice on cement floors in workroom or exposed to drafts causes unnecessary waste.

Keep doors of refrigerator room closed. Do not work in refrigerator more than necessary, and do not leave the lights burning.

Eliminate breakage of glass as much as possible. Bottles broken at the fillers cause the loss not only of the bottles, but of considerable milk, often more than a bottleful. Do not throw away the broken glass if it can be sold to glass blowers.

Avoid extra labor by convenient arrangement of rooms and equipment, and by use of labor-saving devices, when practicable.

Avoid as much as possible agitation of the milk in handling.

MILK-BOTTLE LOSSES.

The loss of bottles at milk plants is an important item. Estimates of the large dealers in five cities were averaged, and, according to their figures, the average life of a glass bottle was $22\frac{1}{4}$ trips. The results are seen in Table 8.

TABLE 8.—*Estimated life of glass milk bottles as given by some of the principal dealers in five cities.*

City.	Number of dealers.	Average trips.	Variation.
Washington	3	12.60	8 to 18
Baltimore	8	18.00	4 to 50
Boston	13	28.50	10 to 50
Philadelphia	10	20.80	6 to 30
Pittsburgh	6	21.60	8 to 40
Average or total	40	22.25	4 to 50

Bottles of various sizes cost (1922) in large lots, on the average, 6 cents each, so that if a plant uses 10,000 bottles and has to replace them every 22.25 days, the expense is \$26.96 a day.

Some dealers now charge their family customers for all bottles not returned and the custom of charging store customers for the bottle is quite common. A ticket is usually given the store customer when he pays for the bottle, and the amount paid is returned upon the surrender of the ticket and a bottle. Where a bottle is returned each time a bottle of milk is taken away no ticket or charge is required. A special bottle is often used for the store trade, and in that case no ticket is required.

One of the means used by dealers in many localities to reduce the loss from stolen or misplaced bottles is the establishment of milk-bottle exchanges. These exchanges are in operation in many of the larger cities, where they serve as a sort of clearing house, mislaid bottles being collected and returned to their owners. The establishments of the milk dealers are visited regularly and all bottles belonging to other dealers are brought to the exchange headquarters, where they are washed, sterilized, and sorted. Usually very little or nothing is paid by the exchange for bottles collected in this way, but sometimes dealers bring in their stray bottles, the price they receive varying from one-fourth cent to 1 cent for each bottle. Bottles brought in by junk dealers, ash men, or other persons are also paid for. The city dumps are visited by employees of the exchange and many bottles are obtained from this source. In one city where the exchange kept a record of the number of bottles thus recovered,

1,500,000 were obtained in three years. The usual charge for bottles returned to the owner is from one-half cent to 3 cents each. Cans, jackets, bottle cases, and other articles which constitute a milk dealer's delivery equipment are also handled by some of the exchanges. In many cases the exchanges are operated by dealers, who generally are stockholders.

In some exchanges a small profit is made, though the object of the exchange is not to make money, but simply to help the dealers recover their bottles, and the latter can well afford to pay the small price asked. While these exchanges do away with but a small part of the large loss of bottles incident to the milk business, yet they are a useful

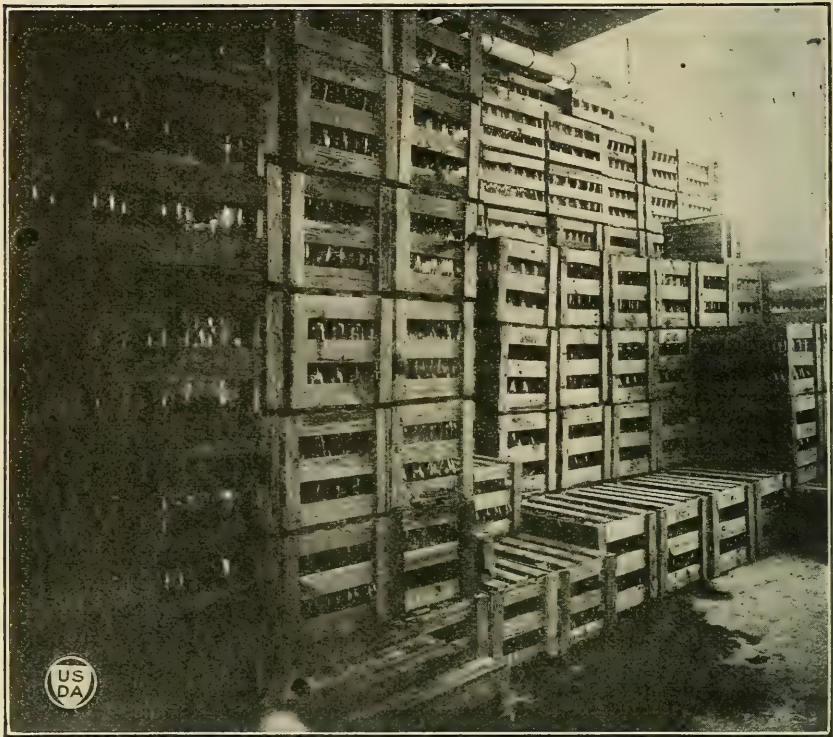


FIG. 20.—Dealers must keep a large supply of bottles on hand. Fifty dealers bought on the average 120 bottles a month for every 100 bottles filled daily.

factor in reducing expenses, and dealers in those cities where such exchanges do not exist would do well to consider this subject with a view to organizing an exchange.

All milk plants should have a system of checking up their drivers on the number of bottles brought back each day. Drivers often become careless even when there is such a system; but if no record is kept, the losses are of course much greater.

People are often ignorant of the value of the bottles and sometimes break them, throw them into the ash barrel, or use them for other purposes. Many dealers send special notices to the consumers in regard to the necessity of returning bottles; this tends to eliminate some of the carelessness.

Many bottles are broken in the plant, though some dealers are helping to eliminate this loss by instructing their men as to the value of the bottles and the need for careful handling. Some keep records of the number broken. Most dealers sell the broken glass to the glass blowers for a certain price per ton, but many small dealers still pursue the wasteful practice of throwing it into the dump. Unless the bottles are too cold when washed, fewer are broken with the large automatic washing machines now in use than is the case with the hand-brush method of washing, for the reason that there is less handling. It is very important that the bottle cases be in good condition and hold the bottles firmly, especially where they are moved on gravity conveyers.

Table 9 is a summary of the replies to a questionnaire on bottle losses of 50 dealers grouped according to number of bottles filled daily.

In some cities the business carried on by junk dealers is one of the worst sources of loss in milk bottles; not only do they sell the bottles to dealers in the city but often ship them to other towns. It is often difficult to get convictions against junk dealers in cities where the stores are charged for bottles, for the reason that bottles used for family trade and belonging to the dealers can not be distinguished from the store bottles which have been paid for. However, if a special bottle were used for the store trade by all the milk dealers this trouble would be lessened.

TABLE 9.—Summary of 50 replies to questionnaire on milk-bottle losses.

Size of plant (bottles filled daily).	Number of dealers.	Average bottles filled daily.	Average bottles bought per month.	Average bottles bought monthly per 100 filled daily.	Average cost of bottles per month. ¹	Average cost per month per 100 filled daily. ¹	Average number bottles lost and broken daily per 100 filled.	Proportion of broken to lost bottles. ²	Trips per bottle. ²
Up to 1,000.....	5	740	523	70.6	\$27.60	\$3.73	4.6	1: 0.8	21
1,001 to 2,000.....	7	1,685	1,114	66.1	51.47	3.05	2.6	1: 1.7	13
2,001 to 5,000.....	5	3,800	5,756	151.5	238.00	6.26	5.0	1: 2.5	14
5,001 to 10,000.....	16	7,906	9,446	119.5	326.50	4.13	3.8	1: 5.3	15
10,001 to 50,000.....	13	23,332	20,135	86.3	1,079.40	4.63	4.2	1: 8.8	17
Over 50,000.....	4	67,500	90,050	133.4	3,071.00	4.55	4.3	1:13.0	19

¹ Based on 1917 prices. ² Dealers' estimates. Estimates were not received from all the dealers.

The problem of keeping down the loss of bottles deserves the attention and study of all dealers. Whatever radical change is made in the system used at present to reduce the loss, cooperation by all the dealers in a particular city seems to be necessary.

The following suggestions have been offered by various dealers and health officers for the solving of the milk-bottle loss problem:

A charge made for every bottle, all dealers to enforce this rule.

The use of single-service fiber bottles only.

Commission to drivers for bottles returned.

Education of consumers as to the great loss.

Efficient milk-bottle exchange.

No bottle, no milk.

Special bottles for the wholesale and store trade, and charge made for the bottle.

Compel the use of bottles with name blown in the bottle. Must be used by the owner only.

Universal interchangeable bottle.

Federal control, as State and city are too lenient.

Forbid the use of bottles recovered from the dumps.

Federal publicity campaign.

Laws prohibiting junk dealers from handling milk bottles.

Laws compelling consumers to return the milk bottles.

Penalty for use of milk bottles for anything but milk.

Use of special bottle cases in the plant to prevent breakage.

GOODS RETURNED FROM DELIVERY ROUTES.

Another source of loss and added expense in the milk business is the large quantity of goods returned from delivery routes and the uneconomical disposition made of the returned goods. Some dealers make special efforts to keep the returns as low as possible, while others do not, probably figuring that it is cheaper to have large returns sometimes rather than to take the risk of having the driver run short and being obliged to send out extra goods by special delivery. It is to the dealer's advantage to keep the returns as low as possible, while at the same time taking proper care of the trade.

The figures in Table 10 were obtained from a dealer operating 25 routes, and show the quantities of the various goods returned, expressed in per cent of those taken out.

TABLE 10.—Quantities of various goods returned at a representative plant with 25 routes, in per cent of goods taken out.

	Goods returned.		
	Total year.	Month of October.	One Monday in October.
	Per cent.	Per cent.	Per cent.
Gallons milk (bulk).....	5.0	2.0	4.5
Quarts milk.....	4.3	4.0	4.5
Pints milk.....	5.2	6.0	7.5
Half-pints milk.....	3.1	4.0	7.0
Quarts certified milk.....	6.4	6.0	6.2
Quarts buttermilk.....	20.0	22.0	26.0
Gallons cream.....	6.6	10.0	12.0
Quarts cream.....	4.0	3.0	6.3
Pints cream.....	16.0	16.0	20.0
Half-pints cream.....	8.8	9.0	11.0
Half-pints whipping cream.....	25.0	23.0	23.2

Among the most common methods of disposing of returned goods are the following:

Sell the same day as cash sales at the plant or for special orders.

Sell to peddlers the same day.

Sell on the wholesale routes the next day.

Sell on the retail routes the next day.

Separate and sell the cream to the trade the next day.

Separate and sell cream to ice-cream dealers or butter stores, or dispose of it at the butter, ice cream, and cheese departments of own plant.

Sell sour cream to certain classes of trade for family use.

Sell sour milk to cottage-cheese dealers.

Use in the manufacture of casein, milk sugar, albumen, etc.

Use in the manufacture of buttermilk.

Each dealer has to study his own conditions, since what may be the best way for one dealer may not be suitable for another. Most

dealers seem to favor the method of dumping all returns and disposing of the cream for butter and ice-cream purposes. A second grade of buttermilk obtained by making butter from this cream can also be disposed of to bakeries. In this way returns are handled at small expense, and the danger of old milk going out to the trade from this source is eliminated. Using returned milk a second time on delivery wagons is a practice to be discouraged.

Among the methods used to keep the returned goods as low as possible are the following:

Use the quantity of goods returned by the route salesman as one of the points on which his commission is based. This, however, should be counterbalanced by a commission on sales so that there will be an incentive for the driver to take out enough to supply his customers.

Give prizes of different amounts each month to drivers who return the least during the month.

Require drivers to pay 1 cent per bottle for all goods returned above 6 per cent of that taken out.

SHRINKAGE IN HANDLING MILK.

The shrinkage of milk in handling is an important item and every effort should be made to keep it as low as possible. The following table gives the shrinkage for a series of days at three plants.

TABLE 11.—*Shrinkage of milk at city plants.*

	Daily receipts at plant.	Quantity bottled.	Daily loss.	
	Gallons.	Gallons.	Gallons.	Per cent.
Plant No. 1.....	1,221	1,184	37	3.0
	1,000	976	24	2.4
	1,200	1,162	38	3.2
	1,100	1,071	29	2.6
Average.....	1,130	1,098	32	2.8
Plant No. 2.....	1,324	1,299	25	1.9
	1,295	1,274	21	1.6
	1,492	1,468	24	1.6
	1,395	1,385	10	.7
Average.....	1,376	1,356	20	1.4
Plant No. 3.....	1,049	1,004	45	4.3
	1,021	979	42	4.1
	1,087	1,046	41	3.8
Average.....	1,052	1,009	43	4.1

At one small plant where the milk was received by weight and pasteurized in a vat the loss in pasteurizing and bottling was as follows:

	Quarts.
Milk received, 1,254 pounds.....	583
Received from filler.....	572
Shrinkage.....	11
or 1.9 per cent.	

As the milk was received by weight, this loss was nearly all due to carelessness. By taking special care for one day, the plant operator was able to reduce the shrinkage to 0.53 per cent. This was the actual loss in pasteurizing and bottling when the milk was handled carefully.

Losses from shrinkage as reported by 115 dealers varied from 0.3 per cent to 7 per cent, and the average was 2.29 per cent. Such losses are largely due to the following causes:

- Leaky cans.
- Dented cans.
- Cans not full.
- Careless handling of cans in transferring from cars and dumping.
- Inefficient draining of cans.
- Leaky or battered apparatus.
- Fillers out of repair, and leaky valves.
- Losses at the filler. These may be caused by improperly adjusted valves, carelessness in handling, breakage of bottles, etc.
- Carelessness in handling full cases of milk, thus breaking the bottles.
- Loss from milk left in the pasteurizer, pipes, pumps, tanks, or other apparatus.
- Loss from process of pasteurizing, separating, homogenizing, and clarifying, by evaporation and mechanical losses.
- Loss by transferring milk and cream from bottles to cans, as in the case of returns from the routes.
- Shrinkage in cooling milk.
- Breakage of bottles in transferring on conveyers usually due to poorly constructed cases.

There is necessarily a certain amount of shrinkage in transferring milk from cans to bottles and in the process of clarifying and pasteurizing. Special attention to this matter, however, should reduce these losses considerably. Collecting pans should be placed under all milk apparatus where milk is apt to spill and especially under the filling machines.

CHECKING MILK THROUGH THE PLANT.

Every milk plant, whether large or small, should have as a part of an adequate accounting system a method of keeping a check on all milk received and handled through the plant. On the following pages are given some of the forms that may be used in checking the milk handled at small plants. No attempt is made to describe the general accounting system.

CHECKING GOODS HANDLED IN PLANT.

There are many milk losses connected with a milk plant that are sometimes overlooked. For example, a driver may go out with more milk than is charged to him, or he may receive credit for returning more milk than he actually returns, or a quantity of milk may be sent out "special delivery" and fail to be charged. To check up such mistakes and losses a balance of all goods handled at the plant should be made out each day. Figure 21 is a stock balance sheet that is adaptable for a small dealer operating from 5 to 10 wagons.

The method of using this stock balance sheet is as follows: The "stock on hand" may be taken at any definite time, depending upon conditions in the plant, as at 6 p. m.; but it should be at the same time each day. (The "stock on hand" at the bottom of the sheet will be carried forward to the following day as the "stock on hand" at the top of the new sheet.) To this item is added all goods received at the plant during the day. The total of these items is the total to be accounted for. On the credit side of the balance are put all sales, known losses, etc.; this total added to the quantity on hand should equal the total to be accounted for. If all records are care-

fully kept each day this balance should show only a small quantity over or short. In case an extra large quantity is found short on any day, the plant superintendent knows that something is wrong somewhere; either some item was not charged or a leak has occurred, and it is for him to find where it is.

Form L.

192

DAILY BALANCE OF STOCK.

	Milk.				Cream.					But- ter- milk.	Skim milk.	But- ter.	Eggs—Dozen.	Tickets.
	Lbs.	Gals.	Qts.	Pts.	Lbs.	Qts.	Pts.	Half pts.	$\frac{1}{2}$ pts.	Gals.	Gals.	Lbs.		
On hand 6 p. m. previous day														
Received from producers														
.....														
.....														
Total to be accounted for														
Disposition made of milk														
.....														
Sales Route No. 1.....														
Sales Route No. 2.....														
Sales Route No. 3.....														
Sales Route No. 4, etc.....														
Plant sales.....														
Special deliveries.....														
Manufactured.....														
Separated.....														
Spilled.....														
Broken.....														
.....														
Total.....														
On hand 6 p. m.....														
Over.....														
Short.....														

Fig. 21.—Form for checking goods handled through plant.

If a system like this is followed, many unnecessary losses may be eliminated, and the plant superintendent will know each day just how he stands. A monthly balance sheet similar to this one may be used also as a check on the losses for the month.

CHECKING THE DRIVER.

Each driver should be charged with the goods he takes out on his route and should be credited for all goods returned. The forms A and B (Fig. 22) may be used to check the routes out and in.

When the driver comes in from his route he makes out his order for the following day on Form A. (Fig. 22.) This quantity is put up the same day by the plant, and the driver is given exactly this amount when he loads the following morning. If changes are made before the driver leaves, these may be noted under "Extras."

FORM A.—DRIVER'S ORDER.

Route..... Wanted..... 192 .

	Milk.			Cream.					Butter-milk.	Skim milk.	Butter.
	Gals.	Qts.	Pts.	Gals.	Qts.	Pts.	$\frac{1}{2}$ Pts.	$\frac{1}{4}$ Pts.	Qts.	Gals.	Lbs.
Order.....	15	205	105				15		20		5
Extras.....	5	5									
Total.....	20	210	105				15		20		5

FORM B.—DRIVER'S RETURN RECORD.

Route..... Returned..... 192 .

	Milk.			Cream.					Buttermilk (Gals.).	Skim milk (Gals.).	Butter (Lbs.)	Bottles returned.			
	Gals.	Qts.	Pts.	Gals.	Qts.	Pts.	$\frac{1}{2}$ Pts.	$\frac{1}{4}$ Pts.				Qts.	Pts.	$\frac{1}{2}$ Pts.	$\frac{1}{4}$ Pts.
Returned.....	10	10	5				5				5	150	150	20	
Returned 2nd trip.....															
Total.....	10	10	5				5				5	150	150	20	

FIG. 22.—Forms for checking driver out and in.

On his return from the route the driver enters the quantity of goods returned on the return record, Form B. (Fig. 22.) The difference between the totals on Forms A and B is the amount of net sales for the day or the amount the driver must account for.

CHECKING THE SHIPPING AND RECEIVING CLERKS.

At some plants it is important that the man who delivers the goods to the drivers and the one who receives the returns from them should account for all goods handled or received. Form H (Fig. 23) is an example of a form that may be used to check the shipping clerk; and Form K (Fig. 24), one that may be used to check the receiving clerk.

Form H.

Date.....

BALANCE OF SHIPPING CLERK.

	Milk.			Cream.					Butter-milk.	Skim milk.		Butter.	Cheese.
	Gals.	Qts.	Pts.	Gals.	Qts.	Pts.	$\frac{1}{2}$ pts.	$\frac{1}{4}$ pts.	Qts.	Gals.	Qts.	Pounds.	Pkgs.
On hand, 6 p. m.													
Delivered to Route 1.													
2.													
3.													
4.													
5, etc.													
Cash sales.													
Broken or spilled.													
Total.													
On hand 7 a. m.													
Total.													
Over.													
Short.													

FIG. 23.—Form for checking shipments taken out by drivers.

Form K.

BALANCE OF RECEIVING CLERK.

	Milk.			Cream.					Butter-milk.	Skim milk.		Butter.	Cheese.
	Gals.	Qts.	Pts.	Gals.	Qts.	Pts.	$\frac{1}{2}$ pts.	$\frac{1}{4}$ pts.	Qts.	Gals.	Qts.	Pounds.	Pkgs.
On hand 6 a. m.													
Received from Route 1.													
2.													
3.													
4.													
5, etc.													
Total to account for.													
Turned in to butter department.													
Turned into by-products.													
Other deliveries.													
On hand 6 p. m.													
Total.													
Over.													
Short.													

FIG. 24.—Form for checking the man who receives the returns from drivers.

NUMBER OF MEN REQUIRED TO OPERATE MILK PLANTS.

The average number of workmen employed in a milk plant, also of route foremen, office clerks, etc., is shown in Table 12 for 153 plants of various sizes. Wide variations occur in plants of similar sizes, but a general idea may be obtained from this table for purposes of comparison.

TABLE 12.—*Number of men employed in 153 milk plants of various sizes.*

Gallons milk handled daily.	Number of plants.	Plant employees (not including office force).		Delivery routes.			Administrative force.		Office force.		
		Average gallons handled daily per plant.	Average men per plant.	Average number routes per plant.	Average number routes per 100 gallons handled daily.	Average number routes per route foreman.	Average per plant.	Average per 100 gallons handled daily.	Average per plant.	Average per 100 gallons milk handled daily.	Average number of routes per office employee.
Up to 100.....	4	85	1.0	1.0	1.2	.....	.....	.....	.....	.....	.....
101 to 250.....	18	168	1.7	2.4	1.4	.....	0.52	0.31	0.52	0.31	4.7
251 to 500.....	31	390	2.8	4.4	1.1	.....	.74	.19	.77	.20	5.7
501 to 1,000.....	35	788	5.7	9.8	1.2	6.7	1.1	.14	2.7	.34	3.7
1,001 to 1,500.....	15	1,303	7.2	12.4	.9	6.0	1.0	.08	2.4	.18	5.2
1,501 to 2,000.....	11	1,745	11.5	20.5	1.2	7.0	1.4	.08	4.7	.27	4.3
2,001 to 3,000.....	12	2,621	14.6	25.4	.97	8.0	1.3	.05	5.6	.21	4.5
3,001 to 5,000.....	16	3,921	20.5	37.9	.96	7.1	1.9	.05	7.7	.20	4.9
5,001 to 10,000.....	7	7,357	32.7	62.6	.84	7.4	2.1	.03	14.1	.19	4.4
Over 10,000.....	4	17,250	85.8	138.2	.80	9.7	3.0	.02	44.2	.25	3.1

From the average number of routes per 100 gallons the approximate average load carried by the dealers with plants of various sizes can be determined. It will be noted that the larger dealers have fewer routes per 100 gallons handled than the smaller ones. This is owing in part to the fact that in many cases they handled a greater proportion of bulk milk.

The average number of routes per route foreman varied, but as a general rule the larger dealers were able to economize in this respect and more routes were handled per route foreman than in the case of the smaller dealers. The number of administrative officers, also, was proportionally larger at the smaller plants. The number of office employees required in proportion to the number of routes depends more on the system of accounting used than on the size of the business. Some of the large dealers have many more office employees per route operated than some of the smaller ones.

Table 13 presents some interesting information as to the number of men employed in plants in different cities. Figures from the principal plants in each city were obtained.

TABLE 13.—*Men employed in plants in different cities.¹*

Location of plant.	Average number routes per route foreman.	Average number routes per office clerk.	Average number routes per stable-man. ²	Average number gallons handled per milk handler. ³	Average number routes per milk handler. ³
Buffalo.....	7.0	6.5	7.0	125	1.8
Milwaukee.....	12.2	6.3	6.3	212	2.1
Minneapolis and St. Paul.....	9.5	7.9	-----	204	2.0
Cleveland and Akron.....	44.5	4.5	7.5	167	1.5
Baltimore.....	7.5	6.4	5.0	186	2.3
Philadelphia.....	7.0	7.0	9.7	216	1.7
Washington.....	-----	3.0	7.3	171	1.7
Boston.....	6.3	4.3	4.6	288	1.5
Pittsburgh.....	6.1	3.9	5.1	317	2.1
Detroit.....	10.2	6.4	10.1	271	2.0
Seattle.....	9.3	4.7	8.6	200	1.8
Spokane and Butte.....	10.0	2.5	10.0	123	1.4
Portland, Oreg.....	44.1	6.8	-----	140	2.1
Los Angeles and San Francisco.....	7.6	5.9	-----	277	2.0

¹ According to data collected in 1916-17.

² As a general rule, horses and wagons are used for retail milk delivery, and these figures indicate the number of men required to take care of the horses.

³ Under this heading are included all men in the plant whose work deals with the milk department, including engineers and firemen.

⁴ Includes collectors and solicitors.

SYSTEMS OF BUYING MILK.

A few years ago by far the larger part of the milk handled by city dealers was bought from producers on the basis of the measure, that is, the can or the gallon. Dealers as well as producers have come to recognize the inaccuracy of this system and its unfairness, both to the buyers and to the farmers, so that in recent years the tendency has been to abandon it and adopt systems that are more nearly equitable and at the same time practicable.

The following bases are those in common use:

By the quart or gallon.

By the can, the size of the can varying from 8½ to 40 quarts or more.

By the can or the gallon, with a minimum standard for butterfat and a definite premium per gallon for each one-tenth per cent butterfat above standard.

A certain price per point butterfat per gallon.

Same as third way stated above, but with addition of a minimum standard for dairy farm score, and premium for extra points in this score.

By the can, the can of milk being required to come up to a standard weight.

By the gallon, the number of gallons being determined by dividing the weight by 8.6.

By weight, which is determined by the number of cans, each can being supposed to hold a certain quantity of milk by weight.

By weight, the milk being weighed at receiving station or at city plant. The milk is usually dumped into a tank for weighing. In some cases it is weighed in the cans and the weight of cans (tare) is deducted from the total weight of cans and milk.

On the weight basis, with a minimum standard for butterfat and a premium for extra points. Sometimes the butterfat standard is established and additions or deductions are made for each one-tenth per cent above or below it. In some cases the premium is paid only for milk of three-tenths per cent or more above the standard, while the deductions begin at one-tenth per cent below.

A certain price per 100 pounds as base price, the base price being fixed differently for each month in accordance with the average butterfat content of the milk in that month, as shown by the experience of previous years; and a variation in the price per 100 pounds of from 4 to 8 cents for every one-tenth per cent butterfat above or below the standard butterfat content for that month. If milk is below 2.8 per cent butterfat, only its butterfat is paid for. If any milk contains less than 8.5 per cent solids-not-fat, a suitable deduction is made. The price allowed per point butterfat is usually higher in winter than in summer.

Grading milk, and paying a price for Grade B per 100 pounds consisting of 3 to 4 cents per one-tenth per cent butterfat; for Grade A, an additional 5 cents per 100 pounds; and for Grade C, 5 cents less per 100 pounds. Grades to be determined on basis of (1) bacterial content, (2) sediment, (3) acidity, (4) flavor and odor, and (5) temperature on arrival in city.

So much per pound butterfat.

A certain price for a pound of butterfat and for 100 pounds of skimmed milk.

Same as above, except that the weight of the whole milk is considered instead of the skimmed milk.

So much per point (one-tenth per cent butterfat).

Milk should not be bought on a measured-gallon basis. Whether it is paid for by the gallon or by the pound it should be weighed at

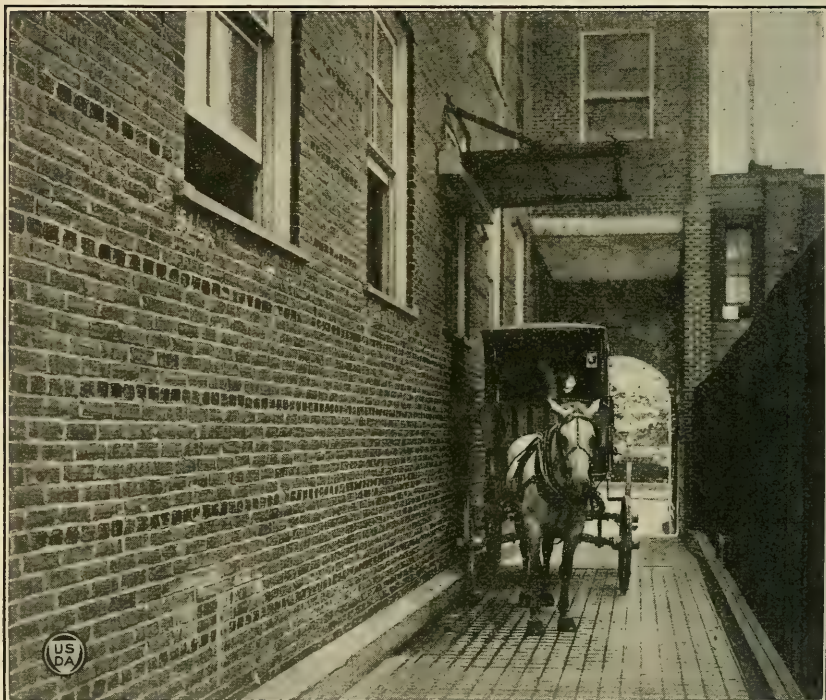


FIG. 25.—Unloading delivery wagon. The driver puts the cases of empty bottles through the small door to the conveyer. At eight plants using this system an average of 30 wagons was unloaded per hour.

the plant. If the milk is paid for by the gallon, the weight can readily be reduced to gallon measure.⁸

The butterfat is the most valuable constituent of milk and is being considered more and more as a basis in paying for the milk.

In 1914 a survey was made in four of the larger eastern cities and of the 87 plants visited 60 were making no attempt to weigh the milk. The proportion of dealers who are using the weight system is much larger now than at that time, yet a large number of dealers still use the can-measure system of determining the quantity of milk received from the producer.

The producer should receive full credit for all milk shipped, but the aim should be to use a system that is accurate and fair to both

⁸ See U. S. Department of Agriculture Bulletin No. 890, "Milk-Plant Equipment."

parties. Naturally the dealer does not want to pay for more milk than he receives, and the farmer wants to receive payment for the full quantity of milk shipped.

In an investigation carried on in 1920 some interesting data were obtained which illustrated the inaccuracy of the method of determining the quantity of milk received at the plant by can measure alone. Observations were made on a total of 346 shipments of milk consisting of 1,102 cans. The cans of milk were examined on arrival at the plants before they were dumped into the weigh cans. The quantity of milk by measure in cans that were not full was estimated by means of measuring sticks, so that regardless of the quantity shipped by the producers and the amount lost before the milk reached the plants, an accurate check was made upon the fullness of the milk



FIG. 26.—Weighing milk. One man does nothing but record the weights. Note overhead-lever type of scales.

cans before they were emptied into the weigh cans. The table shows the difference between the quantity of milk dumped, as determined by can measure, and the actual quantity received, as shown by the scales.

Difference between can-measure and actual-weight receipts of market milk in 346 shipments.

Number of cans.....	1.102
Quantity received, by can measure.....	gallons.. 6.185
Quantity received, at 8.6 pounds to gallon.....	pounds.. 53.191
Quantity received by actual weight.....	do... 52.191
Difference.....	do... 1.000
Per cent of shortage.....	1.88

Thus the shortage in the total quantity of milk received was 1,000 pounds, or 1.88 per cent. The difference no doubt was due primarily

to the poor cans that were used. It can not be expected that dented and battered cans will hold the full amount. One shipment of 6 full cans supposed to hold 30 gallons held only 28½ gallons as shown by the weigh can. These cans were old and were badly dented and battered.

In justice to the producer at plants where milk is weighed, the scales used should be tested from time to time for accuracy, and the milk should be well drained from the cans into the weigh can.

DISPOSAL OF SURPLUS MILK.

Although in many cities systems of paying for milk have been worked out whereby the prices paid have a tendency to induce farmers to adjust their production more nearly to the city demands for market milk and reduce the surplus received, the surplus problem is nevertheless an important one for the milk-plant manager.

The greatest amount of surplus milk is received in most cities in the spring and early summer months. As illustrated in Table 14, unusually large quantities of milk were received in Boston, Philadelphia, and Pittsburgh from May to September, and the greatest surplus occurred in the months of May, June, and July; while in the case of Detroit, where there is a considerable demand for milk in the summer, the greatest surplus occurred during February, March, and April.

TABLE 14.—*Monthly receipts and sales of market milk at cities named, during 1918, expressed as percentages of average receipts and sales.*

(Tabulation of figures received from some of the largest dealers in each city.)

Month.	Boston.			Philadelphia.			Pittsburgh.			Detroit.		
	Receipts (in per cent of average monthly receipts).		Sales.	Receipts (in per cent of average monthly receipts).		Sales.	Receipts (in per cent of average monthly receipts).		Sales.	Receipts (in per cent of average monthly receipts).		Sales.
	In per cent of receipts. ¹	In per cent of average monthly sales.		In per cent of receipts. ¹	In per cent of average monthly sales.		In per cent of receipts. ¹	In per cent of average monthly sales.		In per cent of receipts. ¹	In per cent of average monthly sales.	
January.....	P. ct. 77.1	P. ct. 76.8	P. ct. 92.5	P. ct. 79.1	P. ct. 85.2	P. ct. 81.3	P. ct. 38.7	P. ct. 81.9	P. ct. 72.5	P. ct. 97.7	P. ct. 92.8	P. ct. 77.2
February.....	73.6	76.5	87.9	78.6	87.4	83.0	39.5	72.8	65.7	95.7	63.6	74.3
March.....	89.8	71.3	100.0	88.7	79.7	85.3	51.3	64.7	75.9	106.9	66.2	86.5
April.....	98.2	62.0	95.0	90.6	80.7	88.3	107.0	43.7	107.0	105.1	68.6	88.3
May.....	128.2	51.5	103.2	118.1	70.1	99.8	160.6	28.3	103.9	104.3	82.9	102.9
June.....	148.6	39.0	96.6	126.7	66.2	100.7	158.0	26.7	96.6	102.3	87.1	108.7
July.....	128.7	51.9	104.4	112.8	82.3	112.0	141.7	32.8	106.6	96.8	95.1	112.5
August.....	108.5	71.0	120.3	109.8	87.0	115.2	121.8	41.5	115.7	99.8	95.3	116.1
September.....	96.4	71.9	108.3	102.7	83.9	104.0	107.7	41.5	102.2	91.4	94.1	105.3
October.....	90.5	79.5	112.5	102.6	96.1	119.0	97.6	54.9	122.6	101.7	89.8	111.6
November.....	76.3	75.8	90.4	94.6	93.0	106.1	81.9	63.2	118.5	93.7	93.3	107.0
December.....	84.1	72.3	94.9	95.7	91.2	105.3	94.2	52.4	112.8	104.6	85.9	109.6
Average.....	.....	64.0	.....	.....	82.9	.....	.....	43.7	.....	.....	81.8	.....

¹ The per cent of surplus can be determined by subtracting from 100.

² A large quantity of milk was condensed here.

Each milk-plant operator must determine for himself how to dispose of a surplus to best advantage in his particular locality. Market demands and prices are of course the important factors in determining

what products can be manufactured most advantageously from the milk that can not be disposed of at market milk prices.

The following calculations illustrate how the returns may be figured on various products that can be made from surplus milk. The values here attached to the various products are arbitrary, and the actual prices will depend, of course, to a great extent on the particular locality. The following arbitrary values are used:

Butter.....	per pound..	\$0.50
Buttermilk.....	per gallon..	.20
Cottage cheese.....	per pound..	.05
Sweet cream.....	per gallon..	1.50

Value of by-products from 100 pounds of surplus milk, at assumed prices.

Butter, cottage cheese, and buttermilk:

The cream from 100 pounds of 4 per cent milk will make approximately 4.75 pounds of butter, at 50 cents.....	\$2.38
And 1 gallon of buttermilk, at 20 cents.....	.20
The skim milk will produce approximately 9 pounds of cottage cheese, at 5 cents.....	.45
	3.03

Sweet cream and cottage cheese:

100 pounds of 4 per cent milk will make approximately 2.5 gallons of 20 per cent cream at \$1.50.....	3.75
And approximately 8.75 pounds of cottage cheese, at 5 cents.....	.44
	4.19

Butter and buttermilk:

100 pounds of 4 per cent milk will make approximately 4.75 pounds of butter, at 50 cents.....	2.38
And approximately 10 gallons of buttermilk, at 20 cents.....	2.00
	4.38

Sweet cream and artificial buttermilk:

100 pounds of 4 per cent milk will make approximately 2.5 gallons of 20 per cent cream, at \$1.50.....	3.75
And approximately 9 gallons of artificial buttermilk, at 20 cents.....	1.80
	5.55

Thus with the prices given it would be more profitable for the dealer to separate the surplus and sell the sweet cream and make buttermilk from the skim milk. As stated, however, these figures are given merely for illustration; the cost of manufacture, market demand, and the prices that can be procured for the products must be considered in each case. Such illustrations will assist a dealer in determining what prices he can afford to charge for certain products as compared with prices of other products, as well as in determining what products can be made most advantageously from his surplus milk.

The market for cottage cheese is limited and irregular. Usually there is a good demand for good butter, and many plants are able to make a considerable number of cash sales of butter and buttermilk at the plant. Whether sweet cream can be disposed of readily depends on the locality. Some dealers who have a large surplus manufacture it into less perishable products, such as condensed and powdered milk, casein, etc., but, of course, this practice would not be practicable for a small plant. In the case of all products the relative cost of manufacture and marketing should be considered.

MANUFACTURE OF BY-PRODUCTS.

A milk-plant operator should be familiar with the manufacture of the ordinary by-products.

COTTAGE CHEESE.

For directions on the manufacture of cottage cheese, reference is made to United States Department of Agriculture Bulletin No. 576, "The Manufacture of Cottage Cheese in Creameries and Milk Plants."

BUTTERMILK AND ARTIFICIAL BUTTERMILK.

One of the most economical ways of disposing of surplus milk is by the sale of buttermilk or of artificial buttermilk. Skim milk or sour milk can be utilized profitably in this way. It takes practice and experience to be able to obtain a uniformly good product, but the following notes may be of assistance to those not familiar with the process:

Clean, sweet skim milk or whole milk should be used, and pasteurization is preferable, as it insures a better product from both a commercial and a sanitary standpoint. If skim milk is used better results are obtained if some whole milk is mixed with it, as 1 part whole milk to 3 parts skim milk. Run the milk after pasteurizing into a water-jacketed vat, and add good, clean starter enough to ripen the milk by the time wanted for churning. From 5 to 10 gallons of starter for each 100 gallons of milk should be sufficient. Take particular care to keep a good starter on hand, renewing it as often as necessary. Cover the vat to keep out flies and dirt, and ripen the milk at a temperature of from 60° to 70° F. The ripening temperature depends upon the amount of starter added and the length of time which the milk has to stand. Ripen the milk until it is coagulated into a rather soft curd. If the milk ripens too rapidly, run cold water around the vat to check the process. When the milk is ready, strain it into the churn, and churn for about 20 minutes, or until the butter has gathered in small granules. The milk should be churned at between 55° and 65° F. When butter comes, strain the buttermilk and cool it *at once*, using a cooler if possible. If no cooler is available, put the cans immediately into a tank of ice water or a refrigerator. If possible, bottle the retail buttermilk at once. Whenever possible, use a separate bottler for buttermilk. If not possible, particular care should be taken in washing and sterilizing the machine after buttermilk has been handled.

Further information on this subject is given in United States Department of Agriculture Bulletin No. 319, "Fermented Milks," which may be obtained from the Superintendent of Documents, Government Printing Office, for 5 cents; stamps not accepted.

WEIGHTS OF MILK AND CREAM.

In general the specific gravity of milk and cream depends on the percentage and relation of the solids, the temperature at which the determinations are made, and the age of the milk. The weight of 1 gallon of water at 68° F. (20° C.) according to the Bureau of Standards is 8.32162 pounds. Using this figure as the weight of

water and using the specific gravities of milk and cream of various percentages as given in United States Department of Agriculture Bulletin No. 98, the following table has been worked out as to the weights per gallon, at a temperature of 68° F.

TABLE 15.—*Weight per gallon and specific gravity of milk and cream having various fat contents.*

Commodity.	Fat con- tent.	Specific gravity.	Weight per gallon.	Commodity.	Fat con- tent.	Specific gravity.	Weight per gallon.
	<i>Per cent.</i>		<i>Pounds.</i>		<i>Per cent.</i>		<i>Pounds.</i>
Water.....		1.000	8.32162	Cream.....	20	1.013	8.4298
Skim milk.....	0.025	1.037	8.6295	do.....	22	1.011	8.4132
Milk.....	3	1.034	8.6045	do.....	25	1.008	8.3882
Do.....	3.5	1.033	8.5962	do.....	28	1.006	8.3715
Do.....	4	1.032	8.5879	do.....	30	1.004	8.3549
Do.....	5	1.031	8.5796	do.....	32	1.002	8.3383
Do.....	6	1.030	8.5713	do.....	35	.999	8.3133
Mixed milk and cream...	10	1.025	8.5297	do.....	38	.997	8.2967
Do.....	15	1.018	8.4714	do.....	40	.995	8.2800
Cream.....	18	1.015	8.4464				

Weights are given at 68° F. because that is the temperature used in determining the specific gravities, being equivalent to 20° C., the temperature generally used for such work. There would be a slight difference for milk at 50° to 60° F., the temperature at which milk is usually received at the plant.

The determinations above were made on standardized milk and cream, that is, mixtures of skim milk and cream of various percentages of butterfat. Figures for normal milk containing from 3 to 6 per cent butterfat would vary slightly from those given. For all practical purposes the weight of whole milk may be figured at 8.6 pounds a gallon.

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BULLETIN No. 974

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WM. A. TAYLOR, Chief



Washington, D. C.

PROFESSIONAL PAPER

October 15, 1921

DIRECTIONS FOR BLUEBERRY CULTURE, 1921.¹By FREDERICK V. COVILLE, *Botanist.*

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EARLY EXPERIMENTS WITH BLUEBERRIES.

The experiments which have led to the present publication were begun in 1906. The work of the first four years resulted in a publication entitled "Experiments in Blueberry Culture," issued in 1910.² This work was widely distributed, and a copy came into the hands of Miss Elizabeth C. White, New Lisbon, N. J. Miss White at once perceived the significance of the experiments and the importance of testing their application to the waste lands surrounding her father's cranberry bogs. An informal agreement of cooperation resulted. In 1913 this was replaced by a formal contract, the object of which was to provide suitable conditions for a field test of the blueberry hybrids produced in the course of the experiments at Washington, D. C. The location of the testing plantation is at Whitesbog, 4 miles east of Browns Mills, N. J., in the sandy, peaty, acid soil of the pine barrens. Up to the present time 16 acres have been planted with 27,000 different hybrid seedlings. Thus far, about 18,000 of these

¹ Revised by the writer from "Directions for Blueberry Culture, 1916," which was published as United States Department of Agriculture Bulletin 334.

² The publication mentioned, issued as Bulletin No. 193 of the Bureau of Plant Industry, gave a detailed account of the principles of blueberry culture, including the soil requirements and peculiarities of nutrition of the blueberry plant and the details of the growing of seedlings. It contained 100 pages of text, with 18 plates and 31 text figures. It was reissued in 1911. Both editions are now out of print.

hybrids have fruited and four of them have been selected and approved as worthy of introduction into agriculture. Propagation material from these four hybrids has been placed in the hands of nurserymen for commercial propagation.

Miss White has also brought together at Whitesbog a very remarkable collection of selected wild blueberry plants. Several of these have been used as breeding stocks in the blueberry development work carried on by the department.

In the present bulletin are included such results of the experiments and experience at Washington, Whitesbog, and other points as constitute a brief practical guide for persons desiring to take up blueberry culture.

SPECIAL REQUIREMENTS.

Success in blueberry culture rests especially on the recognition of two peculiarities in the nutrition of these plants: (1) Their requirement of an acid soil; (2) their possession of a root fungus that appears to have the beneficial function of supplying them with nitrogen.

If blueberries are planted in a soil with an alkaline or neutral reaction, such as the ordinary rich garden or fertile field, it is useless to expect their successful growth. In such a situation they become feeble and finally die. Blueberries require an acid soil, and they thrive best in that particular type of acid soil which consists of a mixture of sand and peat.³ (Pl. I.)

Good aeration of the soil is another essential. It is commonly but erroneously supposed that the highbush or swamp blueberry (*Vaccinium corymbosum*), the species chiefly desirable for cultivation, grows best in a permanently wet soil. It is to be observed, however, that the wild plants of the swamps occupy situations which, though perhaps submerged in winter and spring, are exposed to the air during the root-forming period of summer and autumn; or, when growing in permanently submerged places, they stand on a hummock or in a cushion of moss which rises above the summer water level and within which the feeding roots of the bush are closely interlaced. In actual culture, moreover, it has been found that the swamp blueberry does not thrive in a permanently wet or soggy soil.

Although some species of *Vaccinium*, such as the common lowbush blueberry of the northeastern United States, *Vaccinium angustifolium* (called *V. pennsylvanicum* by some authors), grow and

³ The degree of soil acidity best suited to blueberries is about specific acidity 100, corresponding to a hydrogen ion concentration, $P_H=5$. See a paper by Edgar T. Wherry, "Soil Acidity and a Field Method for Its Measurement," published in the technical journal *Ecology*, vol. 1, pp. 160 to 173, July, 1920, with a colored plate. The same subject is treated more fully by Dr. Wherry in the general appendix to the Smithsonian Report for 1920, also with a colored plate, under the title "Soil Acidity—Its Nature, Measurement, and Relation to Plant Distribution."

fruit abundantly in sandy uplands that are subject to drought, the swamp blueberry grows best in soils naturally or artificially supplied with adequate moisture.

These, then, are the three fundamental requirements of successful blueberry culture: (1) An acid soil, especially one composed of peat and sand; (2) good drainage and thorough aeration of the surface soil; and (3) permanent but moderate soil moisture. Under such conditions the beneficial root fungus which is believed to be essential to the nutrition of the plant need give the cultivator no concern, for even if the necessary fungus were wholly lacking in the soil of the new plantation each healthy bush set out in it would bring its own supply of soil-inoculation material.

Next in importance to soil conditions is a convenient location with reference to a good market. The berries should reach their destination without delay, preferably early in the morning following the day of picking. To secure the best prices they should also reach the market before the height of the main wild-blueberry season. A situation to the south of the great areas of wild blueberries in northern New England, Canada, and northern Michigan is therefore desirable. One of the most promising districts for blueberry culture is the cranberry region of New Jersey, for there an ideal soil occurs in conjunction with an early-maturing season and excellent shipping facilities to the markets of Philadelphia and New York.

Situations liable to late spring freezes, such as the bottoms of valleys, should be avoided, for although the blueberry plant itself is seldom permanently injured by such a freeze its crop of fruit may be destroyed.

It has been observed that in or around bodies of water, such as cranberry reservoirs or cranberry bogs temporarily flooded to prevent frost or insect injury, the wild bushes often produce normal crops of blueberries in seasons in which the wild crop of upland blueberries has been destroyed by late spring freezes. Proximity to such bodies of water is evidently advantageous.

In regions subject to very low winter temperatures a blanket of snow sufficiently deep to cover the bushes often protects them completely, when twigs not covered by the snow are winterkilled. In the very cold February of 1918 the fruiting twigs of lowbush hybrids at Whitesbog, N. J., unprotected by snow, were killed by temperatures of about 12° below zero F. Both parents of these hybrids were uninjured at Greenfield, N. H., where the temperature went down to 30° below zero, but the plants there were covered with deep snow. Another observation made in the same season on Crotched Mountain, N. H., merits attention in this connection. Wild-blueberry bushes 6 to 7 feet high, the tops of which projected through

the snow, bore no fruit on the exposed tops in the following summer, while the sides and bases of the same bushes, which had been covered with snow, yielded the usual abundance of berries. The dead fruit buds still remained on the winterkilled twig tips at the exposed tops of the bushes.

IMPORTANCE OF SUPERIOR VARIETIES.

In the southern United States and in the Middle West blueberries are not ordinarily distinguished from huckleberries, but in New England the distinction is very clearly drawn. The name huckleberry is there restricted to plants of the genus *Gaylussacia*, the berries of which contain 10 large seeds with bony coverings like minute peach pits, which crackle between the teeth. The name blueberry is applied in New England to the various species of the genus *Vaccinium*, in which the seeds, though numerous, are so small that they are barely noticeable when the berries are eaten. It is probable that the comparatively low estimation in which this fruit is held in the South is largely due to the lack of a distinctive popular name and the consequent confusion of the delicious small-seeded southern *Vacciniums* with the coarse large-seeded *Gaylussacias*. It is the culture of the small-seeded blueberries only, as distinguished from the large-seeded huckleberries, that is here advocated.

From the market standpoint the features of superiority in a blueberry are sweetness and excellence of flavor; large size; light-blue color, due to the presence of a dense bloom over the dark-purple or almost black skin; "dryness," or freedom from superficial moisture, especially the fermenting juice of broken berries; and plumpness—that is, freedom from the withered or wrinkled appearance that the berries begin to acquire several days after picking.

Although blueberry plantations may be formed by the transplanting of unselected wild bushes or by the growing of chance seedlings, neither of these courses is advocated, because neither would result in the production of fruit of an especially superior quality. Seedling plants, even from the largest berried wild plants, produce small berries as often as large ones. The cultivator should begin with the purchase of a few plants of selected hybrid varieties or by the transplanting of the best wild bushes, selected when in fruit for the size, color, flavor, and earliness of the berry and the vigor and productiveness of the bush. These he should propagate by layering, by division, and by cuttings. Through a combination of these methods, a valuable old plant can often be multiplied by several hundred at one propagation, the fruit of the progeny retaining all the characteristics of the parent.

In making selections among wild bushes it is an excellent plan to preserve for future reference about a dozen of the largest berries in

a tightly stoppered wide-mouthed bottle containing a mixture of 1 part of formalin, or 40 per cent formaldehyde, to 15 parts of water. Each bottle should contain berries from only a single bush or, in the case of a plant that spreads by the root, from a single patch. Care should be taken not to rub the delicate "bloom" from the berries. A small twig bearing two or three leaves, from the same plant from which the berries were taken, should also be placed in the bottle. The Department of Agriculture would be glad to receive such samples and identify them for the sender. Some of the bushes thus located might prove to be of value in the blueberry breeding work of the department.

Great interest has developed recently in Florida on the subject of blueberry culture. Extravagant and misleading statements have been published and thousands of ordinary wild bushes have been sold at high prices, the purchasers being led to believe that the plants were of specially selected or adapted varieties. One company, located near Tampa, published as the frontispiece of a blueberry advertising pamphlet a natural-size illustration of a quart box of one of the United States Department of Agriculture selected hybrids, without designating it as such. The reader of the pamphlet would naturally believe that the bushes the firm was selling would produce such berries as were shown in the illustration. The real success of a single blueberry plantation near Crestview, in northwestern Florida, set with selected plants from the near-by woods, is chiefly responsible for the present wave of blueberry exploitation in that State. The best advice that can be given at present to those desiring to experiment with blueberry culture in Florida is to make certain that any plants they buy are as represented by the seller, to be sure that alleged improved varieties are not in reality ordinary wild blueberries, perhaps inferior to wild bushes that the purchaser might find in his own neighborhood by careful search. The selected hybrids described in this bulletin are of northern parentage and probably will not thrive in Florida because Florida winters are not sufficiently cold to give these plants the chilling they require in winter.⁴ The United States Department of Agriculture has already begun the breeding of improved blueberries from species native in Florida, but it greatly desires better southern breeding stocks than it now possesses. Those interested in the advancement of blueberry culture in Florida are especially urged to make selections among their wild blueberries in accordance with the general directions given in the two preceding paragraphs.

⁴For an account of the experiments that led to this conclusion, see "The Influence of Cold in Stimulating the Growth of Plants," published in the Journal of Agricultural Research for October 15, 1920, vol. 20, pp. 151 to 160, with 16 plates.

PROPAGATION.

While grafting or budding is almost indispensable in experimental work with blueberries, bushes propagated by these methods are not suitable for permanent commercial plantations, because such bushes are continually sending up new and undesirable shoots from the stock. Budding, however, is the best known means of producing a large quantity of cutting wood from a valuable selected blueberry hybrid. It is useful also in testing the quality of a new variety, for a budded blueberry when properly handled comes into bearing two years from the time of budding and doubtless will continue to yield for several years, until the budded stem becomes old and decrepit.

BUDDING.

The best season for budding the blueberry is from the middle of July to the middle of August. The ordinary method of shield budding,⁵ with a T-shaped cut and dry and unwaxed raffia wrapping, has proved the most successful of all the methods tried. (Pl. II.) In selecting budwood, attention should be paid to the following points: A bud forms at the base of each leaf; at first the scales covering the bud are green; when they are a little older they become straw colored, and later brown. When the buds have reached this brown stage they are of the proper age for use. All three stages may occur at the same time on a single branch, and in such a case the upper part of the branch should be discarded. A bud is more easily handled if the tiny leafstalk is left attached to it. Provision for this is easily made by cutting off the blades, but not the stalks, of the leaves when the branches that are to be used for budwood are removed from the parent bush. Care should be taken to discard the large fat flowering buds that occur toward the ends of the branches. In most blueberry plants, however, these flowering buds do not develop until after the budding season.

When blueberry buds are to be inserted the same day on which the budwood is cut, the sticks require no other treatment than to be kept in the shade in the folds of a moist clean towel. The budwood is easily ruined, however, by continued subjection to the high temperatures prevalent at the midsummer budding season. Any budwood that has been cut should therefore be kept on ice at night or at any other time when it is not in actual use.

In carrying blueberry budwood long distances, excellent results have been secured by the use of a thermos bottle. The bottle, opened, and the budwood, in clean moist wrappings and with additional moist packing material, should be kept on ice for several hours

⁵ This and other methods of budding are described in Farmers' Bulletin 157, "The Propagation of Plants," by L. C. Corbett.

until thoroughly chilled. Just before the journey is to begin the chilled budwood and packing material is placed in the bottle and the bottle closed. Immediately on arrival at its destination the bottle should be opened and the contents kept chilled in an ice box until used. By this method blueberry budwood has been kept in perfect condition for more than a week, and probably that period can be much prolonged.

The best wood on which to bud is the lower portion of vigorous basal shoots of the season, especially those from plants that were cut to the stump in the preceding winter or early spring. On such shoots the bark can be lifted with ease much later in the season than on older stems. In taking the bud from the stick of budwood the cut is made just deep enough to leave a thin layer of wood attached to the middle of the bud slice. The raffia should be tied rather tightly, so that the juice almost begins to be squeezed from the soft bark. Special care should be taken that the raffia wrapping does not become wet and fermentation ensue between the raw surfaces of bud and stock. Plants budded in a greenhouse should therefore be watered on the surface of the ground, not on the foliage. In the case of outdoor plants liable to be wet by the rain the bud wrappings can be effectually protected by the use of a piece of strong paraffined paper about 6 inches square made into a little cone about the stem just above the bud wrappings and securely tied there with raffia, the lower part of the cone hanging down around the stem like a little skirt, keeping the rain away from the bud and its wrappings. (Pl. III.)

Union of the bud with the stock should take place in two to three weeks. As soon as the budded stem has increased in diameter sufficiently to cause pronounced choking by the raffia, all the wrappings should be removed. Otherwise the choked stem may be broken off by the wind. If choking does not occur the wrapping may be allowed to remain until spring.

Before growth begins in the following spring the stem is cut off above the inserted bud, which is still dormant. Only the inserted bud should be allowed to grow, all other growth from the stock being promptly rubbed off as soon as it starts. (Pl. IV.) Under this treatment the shoot from the inserted bud is very succulent and heavy, and a wind easily breaks it from the stock, but slice and all. To prevent this, the growing shoot, beginning at a length of 6 to 8 inches, should be tied at intervals to a strong stake.

In greenhouse experiments a growth of more than 8 feet has been obtained in the first season from an inserted bud on a vigorous plant, and when the shoot has been made to branch repeatedly by removing the growing tips (Pl. V) as many as 70 cuttings have

been produced the first year from a single valuable bud. In field practice at Whitesbog about 10 cuttings on the average are produced the first year from a single inserted bud, and in individual cases as many as 30 have been produced. (Pl. VI.)

STUMPING.

The easiest way to propagate the swamp blueberry is by a special process of layering called "stumping." The directions are as follows:

(1) In late fall, winter, or spring, preferably in early spring before the buds have begun to push, cut off at the surface of the ground either the whole of the plant or as many of the stems as it is desired to devote to this method of propagation. The stems that are cut off are discarded, or they may be used for cuttings, as described under "Tubering" or "Winter cuttings."

(2) Cover the stumps to the depth of 2 to 3 inches with a mixture of clean sand and sifted peat, two to four parts of sand to one of peat by bulk. A rough box or frame may be built on the ground to keep the sand bed in place.

(3) Care must be taken that the sand bed be not allowed to become dry except at the surface during the summer.

(4) The new growth from the stumps, which without the sand would consist of stems merely, is transformed in working its way through the sand bed into scaly, erect or nearly erect rootstocks which on reaching the surface of the sand continue their development into leafy shoots. (Pl. VII.) Although roots are formed only sparingly on the covered bases of stems, they develop abundantly during spring and early summer on these artificially produced rootstocks, and by the end of autumn all the shoots should be well rooted at the base. They should remain in place in the sand bed till late winter or early spring, undisturbed and exposed to outdoor freezing temperatures; but the sand should be mulched with leaves, preferably those of red oaks, to prevent heaving in freezing weather and to maintain an acid condition of the soil.

(5) Early in the following spring, before the buds have begun to push, open the bed and sever each well-rooted shoot carefully from the stump. Discard the upper portion of the shoot, making the cut at such a point as to leave on the basal portion about three buds above the former level of the sand bed. If the cut at the basal end of the rooted shoot is not smooth or the wood is cracked, recut the surface with a sharp thin-bladed knife. The discarded upper portion of the shoot may be used for winter cuttings, as described on pages 12 to 14.

(6) Set the rooted shoots in a coldframe or a cool greenhouse in a soil mixture consisting of two parts, by bulk, of rotted upland peat and one part of clean sand. The plants may be set in individual pots if the propagator prefers, the pots being bedded to the rim in the sand.

(7) Cover the frame with muslin or other white shade suspended above the glass, giving the plants plenty of light but little or no direct sunlight, and for the first two or three months keep the temperature at not to exceed 65° F. if practicable. When subjected to high temperatures the newly cut shoots are liable to die and rot from the base upward.

(8) Watering should be as infrequent as practicable, only sufficient to keep the soil moist but well aerated, not soggy.

(9) The frame should receive ventilation, but not enough to cause the new twigs to droop. These are most susceptible to overventilation and to overheating when they have nearly completed their growth. (Pl. VIII.)

(10) After the new twigs have stopped growing and their wood becomes hard new root growth takes place. Then secondary twig growth follows, either from the apex of the new twigs or from another bud lower down on the old wood of the original rooted shoot. Until this secondary twig growth takes place the life of the plant is not assured.

SOIL MIXTURES FOR BLUEBERRIES.

A very successful potting mixture or nursery-bed mixture for blueberry plants consists of one part, by measure, of clean or washed sand, nine parts of rotted upland peat, either chopped or rubbed through a sieve, and three parts of clean, broken crocks—that is, pieces of ordinary unglazed, porous, earthenware flower pots. No loam, and especially no lime, should be used. Manure is not necessary, and in the present state of our knowledge may be regarded as dangerous, although in small quantities it serves to stimulate the plants, at least temporarily. The danger from manure apparently lies in its tendency to injure the beneficial root fungus of the blueberry plant.

The use of broken crocks in the potting mixture is based on the fact that the rootlets seek them and form around them the same kind of mats that they form at the wall of the pot, thus increasing the effective root surface and the vigor of growth. If crocks are not available, the soil mixture should consist of two to four parts of peat to one part of sand.

The peat most successfully used for potting blueberry plants is an upland peat procured in kalmia, or laurel, thickets. In a sandy soil in which the leaves of these bushes and of the oak trees with which they usually grow have accumulated and rotted for many years, untouched by fire, a mass of rich leaf peat is formed, interlaced by the superficial rootlets of the oak and laurel into tough mats or turfs, commonly 2 to 4 inches in thickness. These turfs, ripped from the ground and rotted from two to six months in a moist but well-aerated stack, make an ideal blueberry peat. A good substitute is found in similar turfs formed in sandy oak woods having an underbrush of ericaceous plants other than laurel. The turfs of lowbush blueberries serve the same purpose admirably. Oak leaves raked, stacked, and rotted for about 18 months without lime or manure are also good. The leaves of some trees, such as maples, rot so rapidly that within a year they may have passed from the acid condition necessary for the formation of good peat to the alkaline stage of decomposition, which is fatal to blueberry plants. Even oak leaves rotted for several years become alkaline if they are protected from the addition of new leaves bearing fresh charges of acidity.⁶ The much decomposed peat

⁶ For a fuller discussion of the conditions under which leaves decompose into leaf peat as distinguished from leaf mold, and the fundamentally different effect of the two on the growth of plants, consult "The Formation of Leafmold," Smithsonian Report for 1913, pp. 333 to 343 (also separately printed).

in the submerged lower layers of deep bogs, such as is used for fuel in Europe, is not suitable for blueberry-soil mixtures.

TUBERING.

By ordinary methods cuttings of the swamp blueberry could at first be rooted only in occasional instances. Successful special methods, however, were afterwards devised for these plants. The most novel of the methods devised, but the one easiest of operation, is that of tubering. This method involves the same principle as that employed in stumping, namely, the forcing of new shoots in such a manner that their basal portions are morphologically scaly rootstocks, with a strong rooting tendency. The directions for tubering as applied to the swamp blueberry are as follows:

(1) Make stem cuttings from outdoor plants between midwinter and early spring, before the buds have begun to make their spring growth, and preferably on a warm day when the twigs are not frozen. A still better plan is to make the cuttings in autumn after the leaves have fallen and store them for about two months in moist sphagnum moss or clean basswood sawdust on ice at a temperature just above freezing.

(2) The cuttings are to be made from vigorous plants grown in well-lighted situations and with stems therefore well stored with starch. Use unbranched portions of the old and hardened branches and stems, about a quarter of an inch to an inch, or even more, in diameter. From 3 to 4 inches is a suitable and convenient length. Make the cuts with pruning shears or a fine-toothed saw and remove the bruised wood at the cut ends with a sharp knife. Be careful not to injure the bark or split or strain the wood.

(3) Lay the cuttings horizontally in a box about 8 inches deep in a bed of pure clean sand and cover them to the depth of about three-quarters of an inch with a mixture of sifted rotted peat (two parts) and clean sand (one part). Or the whole bed may be composed of sand mixed with about an equal bulk of peat. Or the bed may consist of a mixture of basswood sawdust and peat, described under "Winter cuttings." Moisten the bed well with rain water, bog water, or other pure water (free from lime) from a sprinkling pot and see that the bed is closely and firmly packed about the cuttings. Cover the box or cutting bed with a pane or panes of glass, the top of the box being flat, so that the glass fits it rather snugly. The box should be so prepared that any surplus water will drain away beneath through holes in the bottom covered with clean broken crocks and sphagnum moss.

(4) Keep the box at a temperature of 55° to 65° F. or as near those limits as practicable. A temperature of 70° or over is likely to ruin the cuttings.

(5) To avoid excessive temperatures, do not allow direct sunlight upon the glass, either keeping the box by north light or keeping it shaded, as by a white cloth or paper cover suspended several inches above the glass, or in a shaded greenhouse.

(6) Keep the air over the bed saturated with moisture. This condition will be evidenced by the condensation of the moisture on the under side of the glass during the cooler part of the day or whenever a cold wind blows against the glass.

(7) Watering should be as infrequent as practicable, only sufficient to keep the cutting bed moist but well aerated and the atmosphere above it saturated. If the glass fits tightly, a second watering may not be needed for several weeks.

(8) Within a few weeks new growth will begin to appear above the soil. (Pl. IX, fig. 1.) When the shoots have reached a length proportionate to their vigor, commonly 1 to 3 inches, their further growth is self-terminated by the death of the tip. After the leaves have reached their full size and acquired the dark-green color of maturity the time has come for the development of roots.

(9) The new growth, which if it had originated above the bed would be like an ordinary shoot, was transformed in working its way through the soil and became a scaly, erect rootstock, which on reaching the surface of the bed continued its development into a leafy shoot. During the spring and early summer roots form in abundance on the lower or rootstock portion of these shoots. (Pl. IX, fig. 2.)

(10) After a shoot is well rooted it commonly, though not invariably, makes secondary twig growth the same season, usually from a bud in the axil of the uppermost leaf. If the rooting of the shoot has not already been ascertained by direct examination, the making of such secondary growth is good evidence that rooting has actually taken place.

(11) When a shoot is well rooted, with roots 1 to 2 inches in length, it is ready to be potted. (Pl. X.) If the shoot has not already disconnected itself from the dead cutting it should be carefully severed with a sharp knife. In the process of tubering the behavior of the cuttings is essentially identical with that of real tubers, like those of the potato. The original cutting dies, but the sprouts that arose from it root at the base and form independent plants.

(12) The rooted shoots should be potted in clean 2-inch earthenware pots in the standard blueberry-soil mixture already described. (Pl. XI.)

(13) The pots should be bedded in moist sand up to the rim in a glass-covered frame or box, well lighted but protected from direct sunlight and slightly ventilated but with a saturated or nearly saturated atmosphere.

(14) To obtain rapid growth, gradually accustom the rooted plants to a well-ventilated atmosphere and then to half sunlight, this adjustment extending over a period of about three or four weeks.

(15) If preferred, the rooted shoots may remain in the original cutting bed until the following spring, the cutting bed being exposed during the winter to freezing temperatures, but mulched with oak leaves, and the plants may then be transferred, with their whole root mat intact, to a peat and sand nursery bed at a spacing of about a foot each way.

Where propagating is to be done on a sufficiently large scale, outdoor coldframes may be used instead of cutting boxes. At Whitesbog the process of tubering has been carried on with great success in muslin-shaded coldframes, and the handling of the cuttings, both before and after rooting, has been such simplified. The cuttings are made in the fall, packed in boxes in loose, moist, clean sphagnum moss or basswood sawdust, and stored during the winter in a cool cranberry house at a temperature of about 40° F. As soon as the frost is out of the ground beds of clean sand are laid down in the coldframes, and the cuttings are pressed into the sand until the upper side is level with the surface. The whole is then covered with an inch layer of sifted peat (about two parts) and sand (one part). At first the frames were completely shaded by clean

white muslin on a framework about 7 feet above the ground (Pl. XII, fig. 1). They are given a small amount of ventilation.

In 1919 and 1920 an experiment was tried at Whitesbog, on the recommendation of Mr. V. A. Vanicek, an expert plant propagator of Newport, R. I., in the use of lath instead of muslin shades. The shades are so constructed that the lath is about 4 inches above the sash of the coldframe, and the distance between the laths is the thickness of a lath, about a quarter of an inch. (Pl. XII, fig. 2.) This construction allows each cutting to receive direct sunlight, but for only a few minutes at a time. The proportion of cuttings that rooted under these lath shades was a little better than that under the muslin shades. It is to be hoped that further experience with lath shades will establish their apparent superiority over muslin shades, for they are less expensive and more easily handled.

The shades and sash are removed in early October, and in late autumn, after most of their leaves have fallen, the rooted plants are taken out of the frames, so that these can be made ready for a new lot of cuttings very early the next spring. The strongest of the rooted plants taken out of the frames are sometimes set at once in their permanent places in the field plantation. The others are placed in nursery beds at a spacing of about 10 inches each way, where they remain during the winter and the following growing season.

The cutting bed should be watered often enough to keep it from drying at the surface.

WINTER CUTTINGS.

The rooting of leafy cuttings of the blueberry in summer is difficult, because in a temperature above 70° F. the cuttings usually blacken and die. With the aid of a shaded greenhouse, winter cuttings can be started early enough to make roots before warm weather comes on. Similar results can be obtained in coldframes so located, sheltered, and manipulated as to prolong their low temperature as late as possible into the season.

The essentials of a successful coldframe for blueberry propagation are as follows: (1) It should be located on the cool, shaded north side of a building or in some other situation where it will not receive reflected heat from neighboring structures. (2) The cuttings should receive an abundance of light but little or no direct sunlight, a condition best obtained in the case of isolated frames by the use of muslin or slat shades. Frames on the north side of a building will also require shade in early morning and late afternoon from March to September. On sunless days all shade should be removed, so that the cuttings will receive as much light as possible. (3) There should be ample space for the circulation of cool air between the frames and the shade. (4) The frames should be kept closed or nearly closed,

with a little ventilation at night to refill the frame with cool air, until the cuttings are rooted. The closing not only keeps the air saturated with moisture and prevents the drying of the cuttings, but it also tends to maintain a cool ground temperature within the frame.

The use of a greenhouse in which to start the cuttings, followed by the transfer of the cutting boxes to coldframes at the beginning of warm weather, permits an even more prolonged protection of the cuttings than can be obtained in either greenhouse or coldframes alone and increases the percentage of rooted plants. The directions for rooting winter cuttings of the blueberry by this method are as follows:

(1) Make the cuttings in late autumn, removing any leaves that have not already fallen.

(2) Make the cuttings from wood of the preceding summer's growth, rejecting such portions as bear the large fat flowering buds. The cuttings are to be made from well-matured unbranched twigs or shoots grown in well-lighted situations and therefore well stored with starch.

(3) About 4 inches is a suitable length for finished cuttings. A sharp thin-bladed knife should be used. In the finished cutting, the upper end of the diagonal cut at the base of the cutting should come just below a sound bud, and the cut at the upper end of the cutting should be about an eighth of an inch above a sound bud. If the cuts are first made with pruning shears, remove with the knife the bruised wood at the cut ends. The diagonal knife cuts should be as short as is practicable without bruising the bark or splitting or straining the wood. To avoid infection of the cuttings, the knife must be kept clean. This may be done conveniently by dipping the blade in alcohol and wiping it on a clean towel. The cuttings must not be allowed to become dry. This is easily prevented by laying them in the fold of a clean moist towel.

(4) The cutting box (Pl. XIV) should be made of sound clean wood, about 8 inches deep inside and of any convenient size, with drainage holes in the bottom. The cutting bed should be laid down over a groundwork of clean broken corks, gravel, or other material that will provide good drainage. On this place about $3\frac{1}{2}$ inches of rather coarse basswood sawdust mixed with about one-fourth its bulk of peat, the whole bed, including the drainage material, being 4 inches or a little more in thickness. Wet the bed thoroughly with clean rain water or other pure water (free from lime) from a sprinkling pot.

(5) With a newly whittled stick or other clean implement punch holes about 3 inches deep in the cutting bed at a spacing of 2 to 3 inches each way, according to the thickness of the cuttings. In setting the cutting in the hole be sure to press it down far enough and firmly enough to make sure that the cut surface at the base is in contact with the sawdust, but be careful not to injure the delicate new tissue at the base of the cutting by pushing it forcibly into the cutting bed. With the stick tamp the sawdust firmly about the cutting. Cover the box with a pane or panes of glass.

(6) To prevent injury of the cuttings by overheating, allow little or no direct sunlight on the boxes. Shade them with muslin or paper or slats so hung as to permit ample circulation of cool air between the shade and the glass.

(7) Keep the air inside the box saturated or nearly saturated with moisture. This condition will be shown by the condensation of the moisture on the under side of the glass at night or at other cool portions of the day.

(8) Watering should be as infrequent as practicable, only sufficient to keep the cutting bed moist but well aerated and the atmosphere in the box saturated. If the glass fits tightly, the period between necessary waterings may extend over several weeks.

(9) Place the box for a month in a temperature of 55° to 60° or 65° F., in either darkness or indirect sunlight. At the end of a month the new healing-over growth, called a callus, should have formed at the base of each cutting.

(10) After the cuttings are callused the temperature in the cutting house should be allowed to run down each night to a temperature of 35° F. or as near that point as the weather permits, but the cuttings should not be allowed to freeze. The day temperature should approach but not exceed 60°. Shade the boxes from direct sunlight, but give them all the indirect light practicable.

(11) After two months of this alternate chilling and moderate warming the buds on many of the cuttings should have begun to push. It is then time to raise the night temperature to 55°, keeping the day temperature at about 60° F.

(12) After new twigs have developed from the upper buds (Pl. XIII) and their growth has been terminated by the browning and shedding of the tips, and the new leaves have reached their full size and acquired the dark-green color of maturity, the formation of roots is about to begin. (Pl. XIV, fig. 1, and Pl. XVI.)

(13) When all or most of the cuttings in the frame have begun to root, ventilation of the box should be begun. The best superficial evidence that a cutting has rooted is the development of secondary twig growth, either from the apex of one of the first set of new twigs or from another bud lower down on the old wood of the cutting. (Pl. XIV, fig. 2, and Pl. XV.) If secondary growth does not take place, the development of a plump but dormant bud at the apex of one of the leafy twigs is also good evidence that the cutting has begun to root. Cuttings that are healthy but not yet rooted at the time ventilation begins usually die from excessive transpiration.

(14) Ventilation should be only slight at first and should be increased very gradually, the transition to full ventilation extending over a period of several weeks. If any of the sensitive secondary growth begins to wilt, reduce the ventilation immediately until the wilting ceases. Be especially careful not to give too much ventilation on windy days. By the time the tips of the secondary shoots are browned and shed and their leaves are mature in size and color, the cuttings have developed sufficient root growth to warrant full ventilation.

(15) All cuttings that are dying should be removed from the bed at once. Those injured by high temperature usually turn brown at the base first, the dead area extending upward until the new growth collapses. Those otherwise sound but suffering from excessive ventilation before they are rooted usually indicate their bad condition by the marginal yellowing of their leaves before they drop and the stems become withered.

(16) The plants are best left in the cutting bed all winter, either indoors at a temperature slightly above freezing, or outdoors mulched with leaves, preferably oak leaves. In early spring, before the buds have begun to push, they should be very carefully lifted and moved, with the whole root mat and adhering soil intact (Pl. XVI), to a peat and sand nursery bed at a spacing of about a foot each way or potted in the standard blueberry-soil mixture.

ROOT CUTTINGS.

The early experiments with root cuttings gave such a small percentage of rooted plants that further experiments in the greenhouse were abandoned. At Whitesbog, N. J., however, in order that the

underground parts as well as the tops of selected wild plants might be utilized, cuttings of these parts were made, about 3 to 4 inches long and of all sizes down to a little less than an eighth of an inch in diameter. These were given the same treatment as tuberous cuttings in coldframes. A good percentage of unusually vigorous rooted sprouts resulted. (Pl. XVIII.) It was found later, however, that most of the pieces that rooted were not true root cuttings, but were from underground portions of stems, properly stem-base cuttings.

MOUND LAYERING.

Wild blueberry plants, and hybrids also, vary greatly in their response to the different methods of propagation here described. Cuttings of the common lowbush blueberry (*Vaccinium angustifolium*) usually do not yield a large percentage of rooted plants. The same is true of hybrids between this species and the swamp blueberry. For these plants the old-fashioned method of mound layering has been found satisfactory. The procedure is simply to cover up the bases of the stems to the depth of 2 to 4 inches with the peat and sand soil in which the plants are growing. If this is done in spring, soon after flowering, the stems are usually well rooted by the end of the season, and each one is ready to be taken off as a separate plant.

TREATMENT OF YOUNG PLANTS.

When blueberry plants, either large or small, are grown in porous pots, the surface of the pot should never be allowed to become dry, for the rootlets which grow through the soil to the wall of the pot for air are extremely fine and easily killed by drying, to the great injury of the plant. This danger may be eliminated by bedding the pots to the rim in a well-drained bed of sand or by setting the pot in another pot of 2 to 4 inches greater diameter, with a packing of moist sphagnum moss between and broken crocks at the bottom.

A burning of the young leaves and growing tips of twigs is often produced by the hot sun from the middle of June to the middle of September. Plants in pots or nursery beds are easily protected from such injury and forced to their maximum growth by a half-shade covering of slats, the slats and the spaces between being of the same width. On cloudy days the shade should be removed. It should not be used in the fall or spring.

During the winter blueberry plants should be kept outdoors, exposed to freezing temperatures, their soil mulched with leaves, preferably oak leaves. When kept in a warm greenhouse during the winter they make no growth before spring. Even then their growth is late, abnormal, often feeble, sometimes deferred for even a whole year.

FIELD PLANTING.

Plants from cuttings or rooted shoots are ready for permanent field planting when they are 1 or 2 years old and 6 to 18 inches high. (Pls. XIX and XX.)

It is a curious fact that these plants send out no new roots in spring until they are in full leaf, when their flowering is nearly or quite finished and their principal twig growth has ceased. It is important, therefore, in taking up either a wild or a cultivated plant from the open ground that as much as possible of the old root mat be carefully lifted with the plant, for upon these old roots the plants depend for moisture until their new rootlets are formed, about two months after the first signs of growth in spring.

In the case of mature wild bushes with very large root systems, when it is practicable to secure but a fraction of the root mat, say a disk only 3 or 4 feet in diameter, it is the best procedure to cut all the stems at the time of transplanting to stumps 1 to 2 inches high. The bush will then produce a new and symmetrical top of a size suited to the capacity of the roots. The wood that is removed may be used for cuttings if the plant is sufficiently valuable.

The stems that make up a bush usually develop fibrous roots on their basal portions beneath the surface of the soil and above the root crown, at which the several stems unite. Such plants can be divided into several when taken up for transplanting. As many as 30 plants, each cut to a stump and with its own small but sufficient portion of the root mat, have been obtained in this way from a large wild plant. By utilizing the various methods of propagation described in this bulletin, as many as 600 cuttings of roots, stems, and twigs have been made from a single very large wild bush.

In resetting plants from which the tops have been removed, the stumps should be made to project about an inch above the surface of the ground. New shoots are formed in spring from such exposed stumps much earlier than from stumps covered with soil and not receiving the warmth of the sun's direct rays. If the plant when reset is made to occupy a moderate depression in the ground, the old stump and the bases of the new stems can afterward be covered with soil, and a new root system will finally develop from the new wood.

When blueberry plants are set out in early spring, before the buds have begun to push, they usually make excellent growth, and for all plants that are pruned to the stump early spring is the best season for transplanting.

Conditions with unpruned plants, however, are different. Since blueberry plants make no new root growth until late spring, it often happens that a period of hot days intervenes between planting and

rooting, and many plants are injured by an excessive loss of water before they have had time to make connection with the water supply of the surrounding soil through the development of new roots. The danger of such injury is greatest in the case of plants transplanted from pots. The old root ball sends up most of its water to the leaves, and in consequence, being at first as a rule in imperfect capillary contact with the new outside soil, the root ball commonly contracts slightly. The contraction is often sufficient to put the roots at the sides and bottom of the root ball permanently out of contact with the surrounding soil, and the plant may continue to suffer severely from drought, although the soil outside the root ball contains plenty of moisture.

An early autumn field planting has furnished a remarkably successful means of avoiding this trouble with potted plants. At this season the excessive heat of summer is over, the plants are in full and vigorous leaf, and, being taken from pots, carry their whole root system with them. The formation of new roots begins at once and proceeds with great activity until the leaves are shed, at the approach of winter. In the spring, when new leaf growth begins, the plants are already well rooted in the soil. They pass through the early hot period without injury and develop remarkable size and vigor by autumn.

In preparing for a field plantation one precaution of special importance must not be overlooked. For the production of a crop of fruit under field conditions, insects are required to carry pollen from one flower to another. The honeybee works little on blueberry flowers. Her tongue is so short that she can not easily reach the nectar. The flowers are pollinated chiefly by bumblebees, whose tongues are long, and by some of the solitary wild bees that are small enough to crawl through the narrow opening of the corolla. (Pl. XXI.) When blueberry flowers are pollinated with pollen from their own bush the berries are fewer, smaller, and later in maturing than when the pollen comes from another bush. Some bushes are almost completely sterile to their own pollen. (Pl. XXII.) The pollen of a plant grown from a cutting is likewise unsatisfactory for the pollination of the parent plant or of other plants grown from its cuttings. It is important, therefore, that a plantation should not be made up wholly from cuttings from one bush. Two stocks should be used, a row of plants from one stock being followed by a row from the other.

In the permanent field plantation bushes of the wild swamp blueberry or its hybrids should be spaced 8 feet apart each way. When they reach mature size they will nearly or quite cover the intervening spaces. When first planted, however, the bushes are preferably set

4 feet apart in the row, with the rows 8 feet apart. (Pl. XXIII.) This spacing permits machine cultivation in one direction. When the bushes begin to crowd each other, every second plant in the row will need to be removed. If the plants are set originally at 4 by 4 feet machine cultivation will be impracticable after the first year or two, and the branches of the bushes are likely to begin to interlock after five or six years.

For lowbush hybrids it seems probable, from the experience at Whitesbog, that a spacing of 6 by 3 feet will give the bushes adequate room for many years. If the bushes ultimately begin to interlace in the rows the removal of every second bush would then leave them at intervals of 6 by 6 feet.

This removal of filler bushes will furnish a large quantity of propagation material, which can be rooted by the various methods described in this bulletin and used for the extension of the plantation.

When blueberry culture is to be tried in a sandy or gravelly soil deficient in peat or peatlike matter, the plants should be set in separate holes or trenches about 12 inches deep in a mixture of two to four parts of peat or half-rotted oak leaves to one part of clean sand. The excavations should be wide enough to provide ample space for new growth of the roots, not less than a foot each way from the old root ball. In small plantings, if the materials for the mixture are easily available in quantity, an 8-inch bed of it may be laid down over the whole surface of the ground, and if a planting is to be tried on a soil wholly unsuited to the blueberry, especially a rich garden soil or a heavy soil affording poor drainage, the area may first be covered with a 2-inch layer of soft-coal cinders, to keep earthworms from bringing up the underlying soil, next a 6-inch layer of sand, for drainage, and finally the 8-inch bed of peat and sand mixture. Wherever used, the peat and sand mixture should be thoroughly manipulated, so as to give it a uniform texture, before the plants are set out in it, for in a soil in which layers of peat alternate with layers of sand the capillary connection of the two is usually imperfect, and a plant rooted in the peat may suffer severely from drought, although the neighboring sand still has water to spare. For a similar reason it is important that when the plant is first set out the peat and sand mixture shall be very tightly pressed and packed about all sides of the old root ball.

To insure full vigor of growth the ground between the bushes must be kept free from all other vegetation. On rocky uplands or in situations deficient in peat a continuous mulch of oak leaves, when it is practicable to procure them, will help toward this end, as well as keep the soil in the necessary acid condition. It is more economical, however, to choose such a location for the plantation

as will permit the use of horse-drawn machinery and will make mulching unnecessary.

The most favorable location for blueberry culture is a moist area with a peat covering and sand subsoil, the peat preferably of such a thickness that deep plowing will turn up some of the underlying sand.

The land should be so ditched or tilled that the water level can be kept at least a foot below the surface of the ground during the growing season.

The ground should be plowed to the depth of 8 to 10 inches and repeatedly harrowed or otherwise tilled during the season preceding the planting, in order to kill the wild vegetation. The best time for such plowing is in late spring, after the principal vegetation has used up its winter store of starch in completing its early growth and before the leaves have matured and the roots have begun the new storage of starch by means of which they could send up new sprouts.

The tillage of the plantation after the young bushes have been set out should be sufficiently thorough to keep down all competing vegetation. This is best done by horse cultivation with a disk harrow, supplemented by careful hand hoeing and hand weeding close about the plants. As the bushes grow older and their roots extend into the spaces between the rows, they develop root mats close beneath the surface of the soil. The tillage over these root mats should be very shallow, not more than 2 or 3 inches. This is probably best accomplished by the use of a small, light spring-tooth cultivator with the teeth set closer together than usual. (Pl. XXIV.)

In case of drought, the drainage ditches may be used to bring in water for subirrigation. But unless the surface of the ground is very level, subirrigation is likely to result in the injury of plants in the lower spots by excess of water. In uneven areas, therefore, surface or overhead irrigation, if accompanied by good drainage, is preferable to subirrigation and should be used if practicable.

Fertilizer experiments have shown that the application of lime or of wood ashes is positively injurious to blueberry plants and that stable manure, while producing a temporary stimulation of vegetative growth, is likely to cause serious injury later.

In greenhouse experiments at Washington it has been found that blueberry plants are greatly stimulated by the application of small quantities of soy-bean meal, either mixed with the soil or applied as a mulch. This material is acid, it has a high nitrogen content, and its nitrogen is in organic form. Blueberry plants to which it is applied in spring, as compared with plants not fertilized, make more

stocky growth and lay down many more fruit buds for the succeeding year.

On an area at Whitesbog in which the proportion of peat to sand was too small to bring about the most vigorous growth of the bushes, an experiment was made in the application, at the rate of 600 pounds per acre, or one-eighth of a pound per square yard, of a special fertilizer which is in successful use in cranberry culture as the result of a series of experiments by the New Jersey State Agricultural Experiment Station. Important characteristics of this fertilizer are its acidity and its comparative freedom from residues of sulphur. The blueberry bushes to which this fertilizer was applied made conspicuously better growth than those that were not fertilized, but they neither grew better nor fruited better than bushes mulched with 1 to 2 inches of rotted peat.

In 1919 and 1920 Mr. Charles S. Beckwith, of the New Jersey Agricultural Experiment Station, conducted a series of fertilizer experiments with blueberries at Whitesbog. The most successful results were obtained with a fertilizer applied in the spring of 1919, made up as follows:

	Pounds.
Nitrate of soda.....	170
Dried blood.....	230
Steamed bone.....	340
Phosphate rock.....	340
Potash.....	170

The yield in 1920 from bushes thus fertilized was more than three times as great as from unfertilized bushes in the same very sandy soil. On the basis of this experiment Mr. Beckwith has recommended the application of this fertilizer at the rate of 600 pounds per acre, or an eighth of a pound per square yard.⁷

As a result of these preliminary fertilizer experiments and in view of the fact that the swamp blueberry fruits abundantly and continuously in soils containing the proper proportion and quality of peat and sand, the use of manure or any chemical fertilizer in such plantations is not at present advocated. But if the proportion of peat to sand is so low that the bushes appear to be suffering for nourishment a mulch of rotted surface peat or half-rotted oak leaves should be applied, or a chemical fertilizer similar in character to the one described above, or some organic nitrogenous substance, such as soy-bean meal or cottonseed meal.

The swamp blueberry does not require a yearly pruning. When one of the stems of a bush becomes unproductive from injury or old age it should, of course, be cut out. If a large part of a bush needs removal it is better to cut all the stems to the ground and let the

⁷ For the details of this experiment, see "The Effect of Fertilizers on Blueberries," published in *Soil Science*, v. 10, pp. 309 to 312, with plate, October, 1920.

plant send up new shoots, all of the same age, to form a wholly new and symmetrical top. With lowbush hybrids it has been found desirable at Whitesbog to remove each year, in late July or early August, immediately after the picking season, all the stems more than 1 year old which have not made vigorous new twig growth during the season. Under such treatment the bushes yield a good crop of berries every year. Farther north, where the growing season is shorter, such pruning should be done in late autumn or very early spring.

It has long been known that the occasional burning of lowbush blueberry areas increases the yield of fruit. In the blueberry canning districts of Maine this has led to the development of a system of burning the blueberry barrens once in three years. In the summer following the burning the plants do not fruit, but they send up from the ground an enormous number of vigorous unbranched big-leaved stems. Late in the season fruit buds are formed in abundance on the upper part of these stems, and in the second summer after the burning the plants fruit heavily. They are likely also to yield fairly well the third summer, but after that they usually become unproductive. The burning should be done in the dormant season when the plants have dropped their leaves and the roots are fully stored with starch and other reserve foods. From these stored materials are formed the vigorous sprouts of the following spring. If an area is burned in late spring or in summer, after the stored food materials have been used up and before the storage for the following year has taken place, the plants will be seriously weakened. The best time for burning is in early spring, before the buds have begun to push. A day should be selected when the upper layers of dead leaves are dry enough to carry a fire and the underlying turf of upland peat is still wet. For if the fire burns so deeply as to consume the layer of peat, from which the plants derive the principal part of their nourishment, their later growth and their fruiting vigor will be seriously impaired. The beneficial effect of burning a blueberry area has led to the idea that wood ashes are a good fertilizer for blueberries. Experiments have shown, however, that one of the most effective ways to kill a blueberry plant is to give the soil an application of wood ashes sufficient to neutralize its acidity. When a blueberry area is properly burned the layer of ashes is very thin, quite insufficient to neutralize the acidity of the underlying peat turf, and therefore harmless, probably indeed under these conditions beneficial. The chief benefits from burning are two, both quite distinct, however, from the fertilizing effect. Burning tends to keep down tree growth and other competing vegetation, and it prunes the blueberry bushes. Burning is by far the least expensive and most effective method known for pruning lowbush blueberries. The procedure is espe-

cially adapted to the management of wild uncultivated areas of the two common lowbush species of the northern United States, *Vaccinium angustifolium* and *V. canadense*. Since the highbush blueberry, *Vaccinium corymbosum*, however, requires drastic pruning only at intervals of many years, and even then at different times for different bushes, burning is not a good method for pruning this species. This is especially true of cultivated plantations, where competing vegetation is kept down by other means.

YIELD.

By proper manipulation in the greenhouse, seedling blueberry plants can often be made to ripen a few berries when they are 1 year old, but they do not come into commercial bearing in field plantations until they are about 4 years old (Pls. XXV to XXIX), when the plants are 1 to 3 feet high. They then increase slowly to full size and full bearing. Wild bushes of the swamp blueberry live to great age, often 50 to 100 years, still bearing heavily, and they often attain a height of 6 to 8 feet when growing in full sunlight; still more when shaded. Individual stems may remain productive from 10 to 25 years. When dead they are replaced by new and vigorous shoots from the root.

The great promise of blueberry growing as an agricultural industry, in just the right soil and under good business management, is indicated by the yields from the oldest of the hybrid plantings at Whitesbog. This planting consists of about a third of an acre, the plants 7 years old in 1919. They yielded in that year at the rate of 96 bushels per acre. The berries sold at a little over \$10 a bushel, in addition to express charges and commissions, the receipts being at the rate of \$966 per acre. In 1920 this planting yielded at the rate of 117 bushels per acre, with receipts at the rate of \$1,280 per acre. These plants were set at 3 by 5 feet and consequently yielded about twice as much per acre at this age as they would if they had been spaced as now advocated, at 4 by 8 feet.

The yields from this planting, from the beginning, are shown in Table I.

TABLE I.—Yield and receipts from a planting of hybrid blueberries at Whitesbog, N. J., 1915 to 1920, inclusive.

Year.	Com- puted yield per acre.	Approxi- mate price per quart.	Value of crop per acre.	Year.	Com- puted yield per acre.	Approxi- mate price per quart.	Value of crop per acre.
	<i>Bushels.</i>	<i>Cents.</i>			<i>Bushels.</i>	<i>Cents.</i>	
1915.....	6.6	18	\$37	1918.....	^a 46.9	30	\$449
1916.....	29.7	22	209	1919.....	95.8	32	966
1917.....	58.3	24	448	1920.....	117.3	34	1,280

^a Yield reduced by late spring frosts.

With beginners in blueberry culture every gradation in accomplishment may be expected, from the great success indicated above to complete failure because of wrong soil, bad location, or poor management.

The heaviest charge against the industry is the cost of producing rooted plants of selected varieties. At the present time plants of the best varieties can not be purchased in acre quantities. The grower must do his own propagating from a few plants. The propagation is sufficiently difficult to demand unusual skill, and it requires constant and painstaking attention.

If the land to be used bears timber and brush the clearing is expensive.

After a plantation is established its maintenance is relatively inexpensive. The cost of cultivation is rather less than that of the staple cultivated crops. The principal charge is for the picking of the berries. At Whitesbog 6 cents a quart has been paid for the last few years. A good picker in an ordinary day picks about a bushel. An exceptionally skillful picker, with unusually favorable bushes, has picked 100 quarts, or more than 3 bushels, in a day. For shipment to the market in crates cultivated blueberries should be picked by hand, never with a "rake" or "scoop," such as is used when blueberries are carted direct to commercial canneries.

HYBRID BLUEBERRIES.

Blueberry breeding has now been carried on for 10 years, with the result that instead of berries the size of peas, like the ordinary wild blueberry, we now have hybrids producing berries the size of Concord grapes. (Pls. XXVII to XXIX.) A few plants out of the 18,000 hybrids that have been fruited at Whitesbog are of the size shown in these illustrations, with berries three-fourths of an inch in diameter. A very few have borne berries even larger, a little more than four-fifths of an inch in diameter, and in the greenhouse a diameter of seven-eighths of an inch has been reached. In the great majority of the hybrids, however, the berries are intermediate in size between ordinary wild ones and the selected hybrids. (Pl. XXVI.) All such small and intermediate hybrids are rejected. Propagation material placed in the hands of nurserymen for commercial propagation is taken from the selected hybrids only.

The unselected hybrid berries vary in color from light blue to dark blue and sometimes shining black, and an occasional bush bears red berries, or even white ones.

The variation of the blueberry hybrids in other respects is also very marked, the plants offering an almost endless opportunity for selection with reference to acidity, sweetness, flavor, juiciness, firm-

ness, productivity, hardiness, season of ripening, resistance to fungous diseases, and many other less important characteristics. In making the selections, special consideration has been given to the form of the bush and its possession of a foliage surface adequate to the nourishment of a large crop of berries. (Pl. XXV.)

CONCLUSION.

The introduction of the blueberry into agriculture has a much more profound significance than the mere addition of one more agricultural industry to those already in existence. Blueberries thrive best in soils so acid as to be considered worthless for ordinary agricultural purposes. Blueberry cultivation, therefore, not only promises to add to the general welfare through the utilization of land almost valueless otherwise, but it offers a profitable industry to individual landowners in certain districts in which general agricultural conditions are especially hard and unpromising, and it suggests the possibility of the further utilization of such lands by means of other crops adapted to acid conditions.⁸

⁸ For a discussion of the principles of acid-soil agriculture in districts in which the cost of lime is prohibitory, consult "The Agricultural Utilization of Acid Lands by Means of Acid-Tolerant Crops," United States Department of Agriculture Bulletin No. 6, 1913.

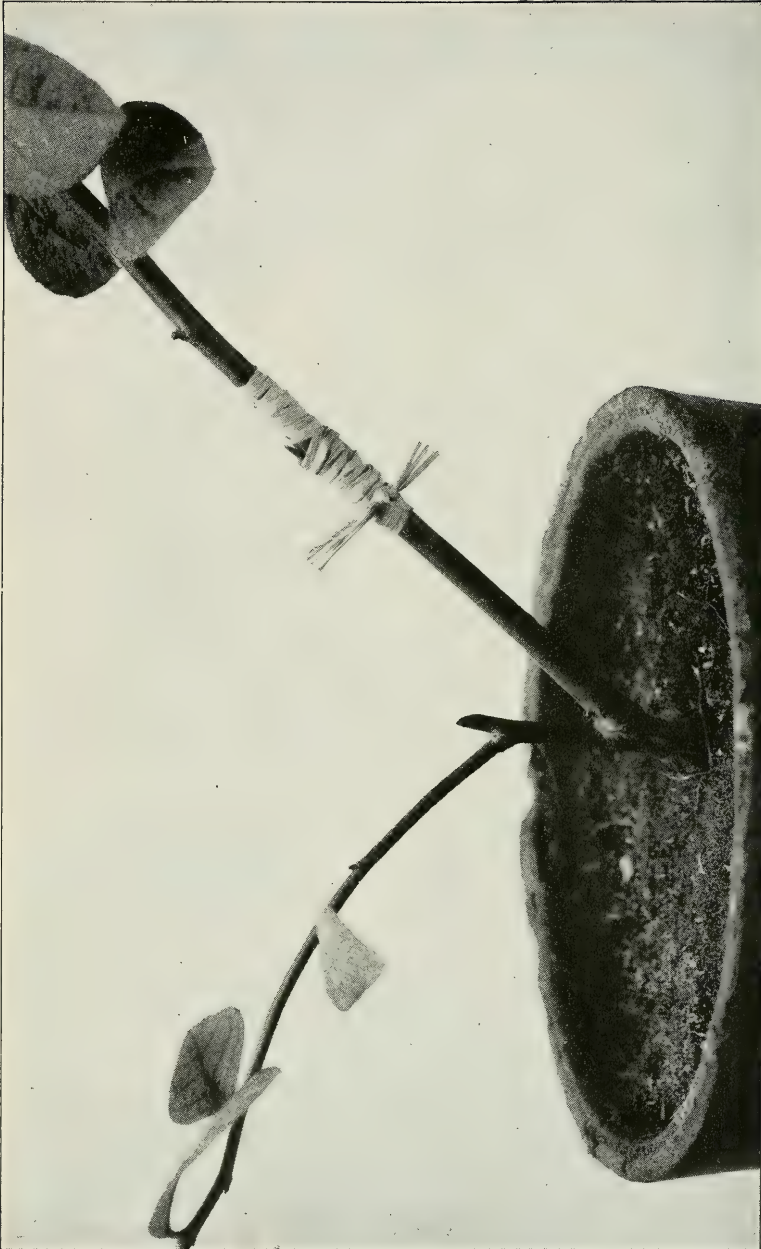
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BLUEBERRY PLANTS SHOWING THE EFFECT OF ACID SOIL AS CONTRASTED WITH RICH GARDEN SOIL.

The three large 1-year-old blueberry plants were grown in a greenhouse in a peat soil. All three are over 24 inches high, the one at the left 27 inches. Standing on the middle pot is a small glass pot containing a seedling of the same age and origin as the others but potted in a rich garden soil. The difference in results shows the fundamental importance of a peaty acid soil for blueberry culture. (One-eighth natural size.)



NEWLY INSERTED BUD ON A BLUEBERRY PLANT.

After loosening the bark of this ordinary plant along a T-shaped cut, a bud sliced from a selected hybrid has been placed in the cut and bound tightly in place with raffia fiber. For detailed directions for budding, see page 6. (Natural size.)



BLUEBERRY PLANT FRESHLY BUDDED IN THE FIELD.

This plant, cut to the ground in early spring, sent up several strong, vigorous shoots. Photographed on July 18 after the insertion, on each shoot, of a bud from a choice variety. The bud wrappings are protected from the rain by a cone of waxed paper tied about the stem. The inserted bud becomes united with the stem in a few weeks and then lies dormant until the following spring.



NEW GROWTH FROM AN INSERTED BLUEBERRY BUD.

Photographed in the greenhouse on March 25. The plant had been budded in the preceding summer. Its top was cut off above the bud when the plant was brought into the greenhouse, late in February. Only the inserted bud is allowed to grow, all others being removed as soon as they begin to swell. The vigor of the whole plant is forced into the growth of the one shoot. (Natural size.)



BUD SHOOT MADE TO BRANCH BY REMOVING ITS TIP.

The principal object of budding is to grow as many cuttings as possible from the inserted bud. A plant with branches yields more cuttings than it would if unbranched, even though the single shoot grew to a greater height. (Natural size.)



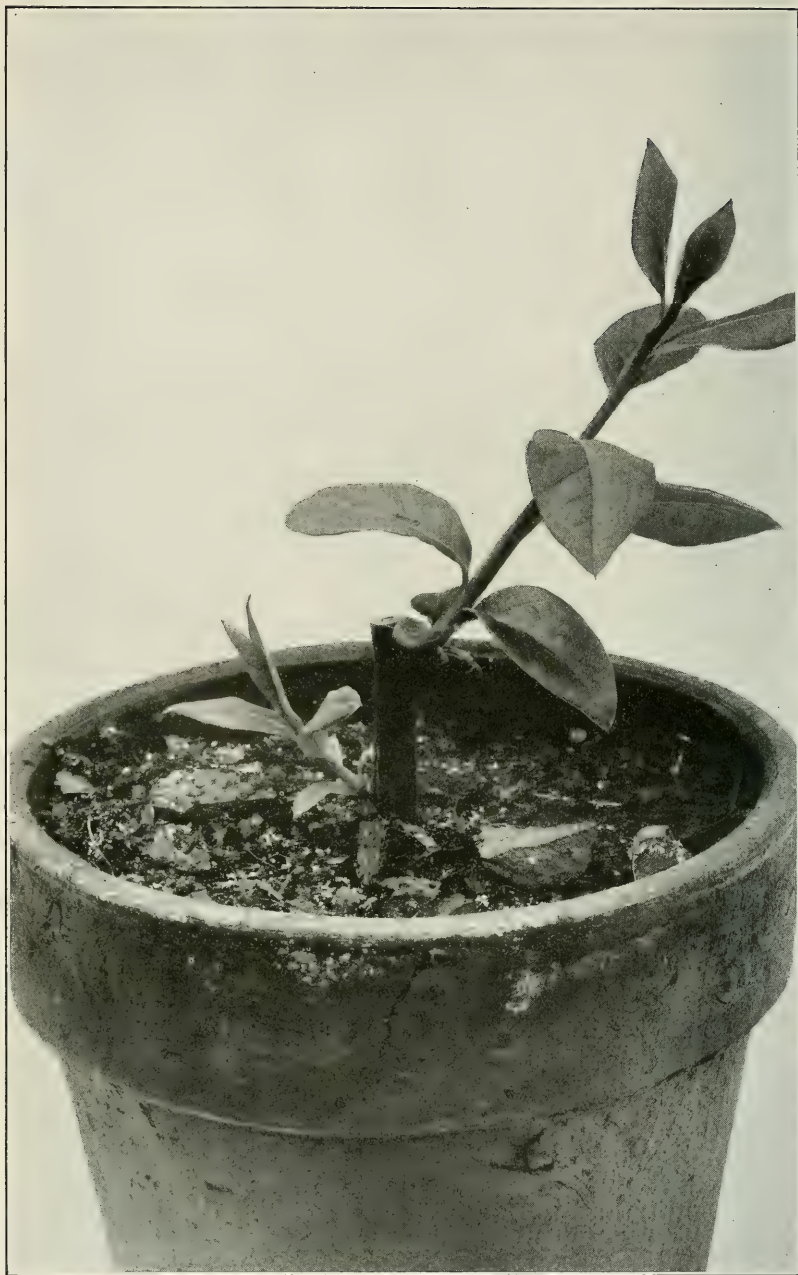
FIRST YEAR'S GROWTH FROM FIVE INSERTED BUDS.

The illustration shows how much cutting wood may be produced in a single year from a budded plant. By using all this new growth for rebudding, the selected variety could be propagated on a still larger scale. Photographed August 3, when the plant was 32 inches high. After that date it made much further growth and a correspondingly larger amount of wood for cuttings.



NEW SHOOTS ON A STUMPED BLUEBERRY PLANT.

The three shoots shown grew after the plant had been cut to the stump. Their white color at the base indicates the depth of the propagating bed through which they forced their way and from which the plant was taken to be photographed. Roots had already begun to develop. (Natural size.)



BLUEBERRY PLANT FROM A ROOTED STUMP SHOOT.

The old cut-off stem shown in the illustration is the rooted base of a vigorous shoot from a stumped blueberry. It was removed from the parent plant a year after stumping, was potted in a 4-inch pot, and when photographed was in process of developing two new leafy branches. (Natural size.)

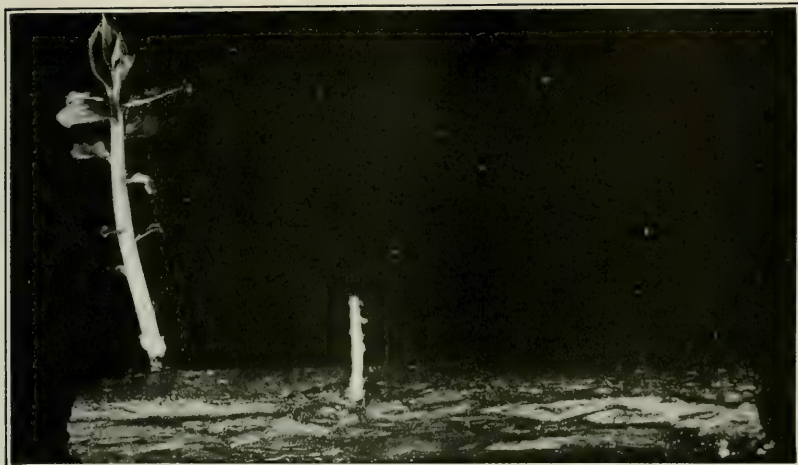


FIG. 1.—TUBERED BLUEBERRY CUTTING WITH YOUNG SPROUTS DEVELOPING.



FIG. 2.—TUBERED BLUEBERRY CUTTING WITH SPROUTS ROOTING AT THE BASE.

The sprout at the left in figure 1 had emerged from the sand and begun to develop green leaves above the surface. The sprout near the center of figure 1 is younger, the whole of it still in the rootstock stage. The two sprouts in figure 2 are developing roots on their lower parts, above the dying wood of the old cutting and beneath the surface of the cutting bed. (Both natural size.)



WELL-ROOTED SPROUTS FROM A TUBERED BLUEBERRY CUTTING.

Sprouts with roots thus far developed are ready for potting, even though secondary growth, as in this case, has not yet taken place. These two sprouts are so closely united that they can not be safely separated into two plants. (Natural size.)



NEWLY POTTED BLUEBERRY PLANT FROM A TUBERED CUTTING.

After the sprout from the tubered cutting had rooted and before it was potted it had made secondary growth from the tip of the original sprout. (Natural size.)



FIG. 1.—BLUEBERRY PROPAGATION FRAMES SHADED WITH MUSLIN.

Each sash is of the standard size, 3 feet wide and 6 feet long. The wooden sides of the cold-frames rise 2 feet from the ground at the back and 1 foot at the front. The lowest part of the roof joists is 6½ feet above the ground.

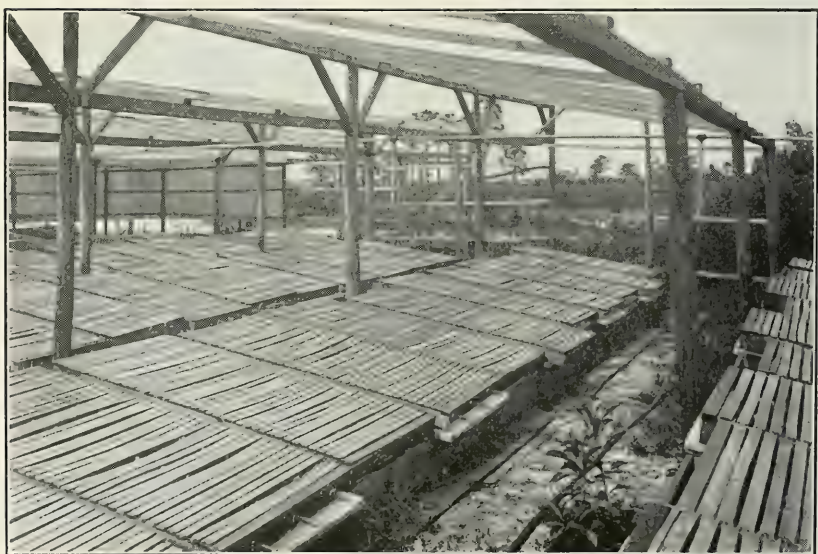


FIG. 2.—BLUEBERRY PROPAGATION FRAMES WITH SLAT SHADES.

Each sash has a separate, removable cover of builders' lath. The laths are separated from each other by a distance equal to the thickness of a lath. The posts shown in the illustration and the framework supported by them were originally made to carry muslin shades. They are not needed when slat shades are used.



BLUEBERRY CUTTINGS IN EARLY STAGES OF GROWTH.

The figure at the left shows a cutting callused at the base and the uppermost bud pushing, but the green bracts and young leaves not yet expanded. In the middle and right-hand figures callusing has proceeded farther at the cut surfaces, both top and bottom, and the formation of new leafy twigs is well under way; but the growth of the tips has not yet been terminated. As shown in the right-hand figure, twigs are often produced from two of the upper buds, sometimes more. (Natural size.)



FIG. 1.—WINTER CUTTINGS SHOWING PRIMARY GROWTH.

The box is 10 by 12 inches by 8 inches deep, inside measurement. The new twigs have completed their primary growth, their leaves have reached full size, and the formation of roots is about to begin. Secondary twig growth has not yet taken place.



FIG. 2.—BOX OF WINTER CUTTINGS SHOWING SECONDARY GROWTH.

Most of the cuttings have put out and matured their strong secondary twigs. This condition of twig growth is conclusive evidence that the cuttings are well rooted and that the box is ready for full ventilation.



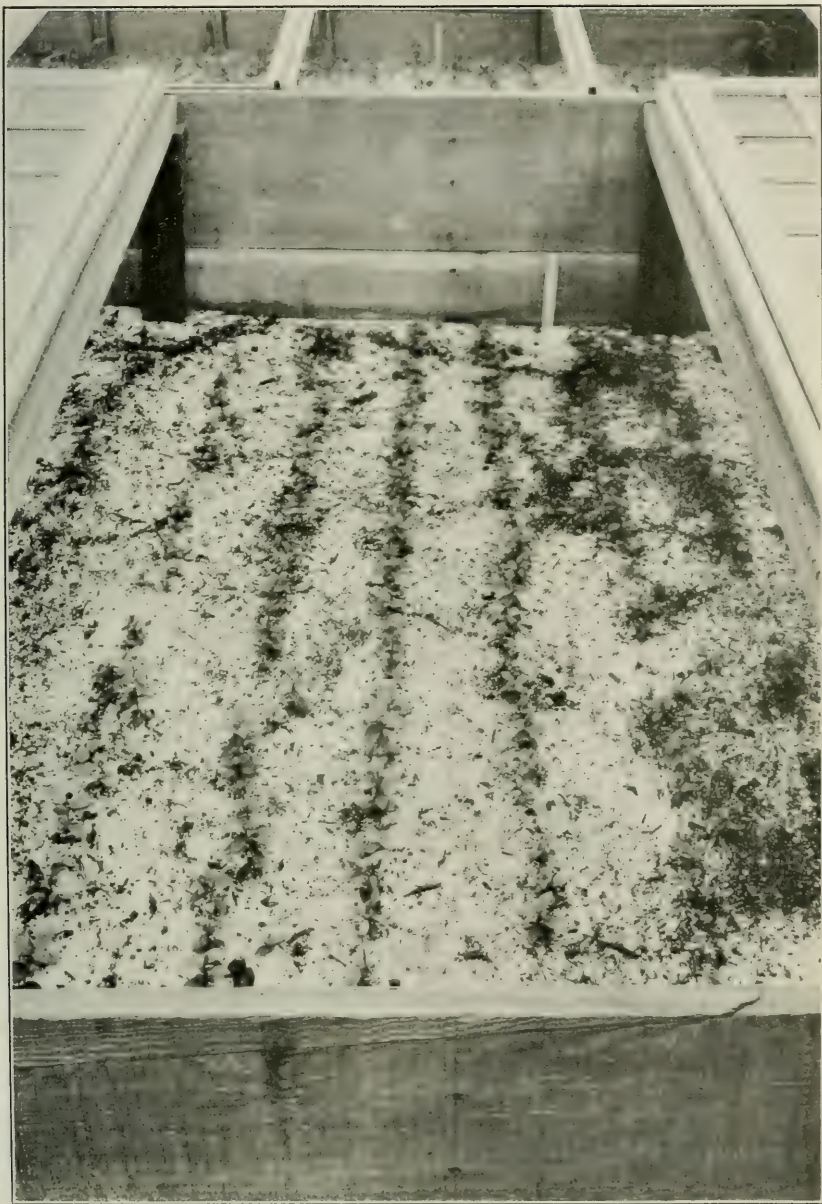
BLUEBERRY CUTTING SHOWING SECONDARY TWIG GROWTH.

The cutting when first made was an unbranched twig. It was callused for a month, then chilled for two months, and then brought again into a temperature of about 60° F. From its stored food the cutting soon put out the short twig shown at the top of the illustration. When the four leaves on this twig had reached mature size and color and were manufacturing new food in the form of starch, roots began to form on the cutting. The roots brought in new mineral food, and then secondary twig growth took place in the form of the younger and stronger of the two twigs. (Natural size.)



WELL-ROOTED BLUEBERRY CUTTING.

This is one of a lot of 12 winter cuttings made on February 12 and set in a cutting box in a mixture of basswood sawdust (four parts) and upland peat (one part). On October 20 all 12 cuttings were well rooted, as shown in the illustration, from a photograph taken on that date, after the leaves were shed and winter dormancy had set in. (Natural size.)



WINTER TWIG CUTTINGS ROOTING IN A COLDFRAME.

The illustration, from a photograph taken on July 21, shows the cuttings at the time the roots are forming. Under this procedure the cuttings are made in the fall, from naked twigs that have just dropped their leaves. They are kept for a month at a temperature of about 60° F., during which time the cut surfaces heal by the formation of a callus. They are then kept at a temperature of 40° F. or a little less. In very early spring they are set in the coldframe, and as the result of their previous chilling their buds begin to swell with the first warm weather and they put out new leafy twigs. Until this new leafy twig growth has been completed, the cuttings can not form roots.



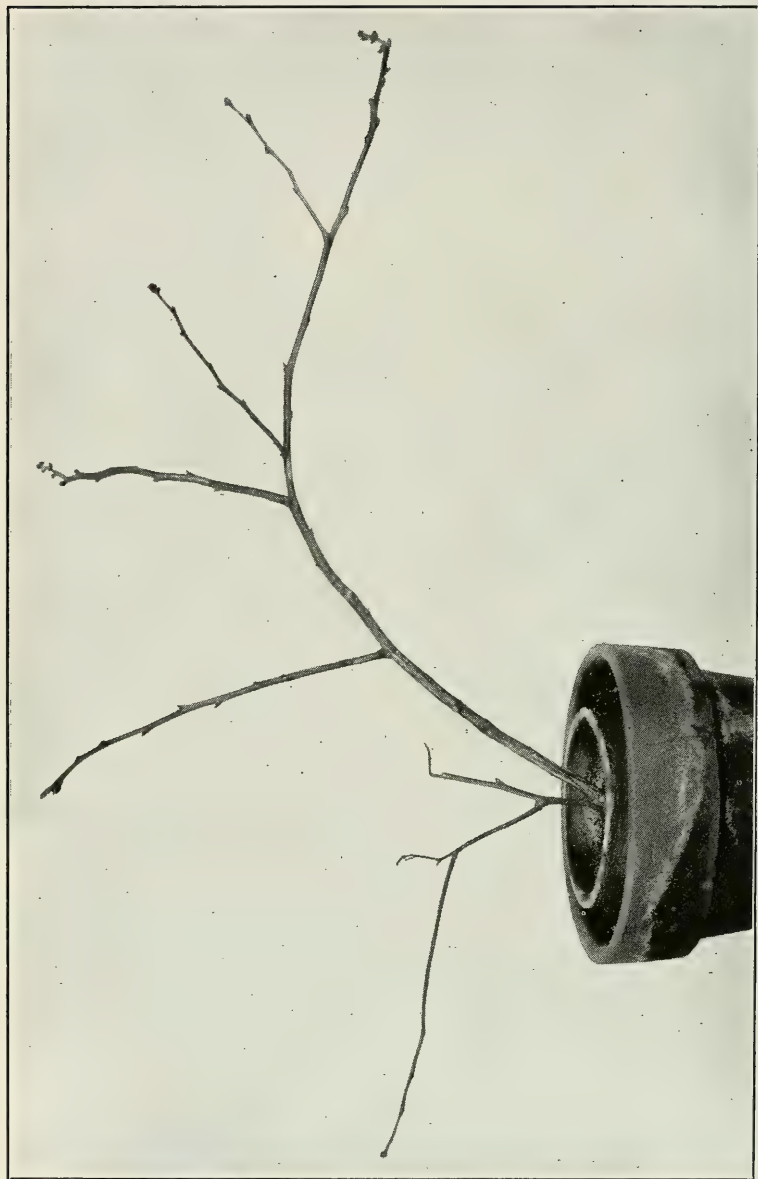
BLUEBERRY PLANTS FROM STEM-BASE CUTTINGS.

The illustration, from a photograph taken on July 27, shows the excellent growth secured from stem-base cuttings buried in a coldframe cutting bed early in the spring of the same year. This section of the coldframe is of the size of a standard sash, 3 feet in width and 6 feet from front to back.



TWO-YEAR-OLD BLUEBERRY PLANTS FROM CUTTINGS.

The plants are in 4-inch pots bedded in sand. Photographed on October 9, when the plants had completed the season's growth and were about to shed their leaves and become dormant. The compartments of the frame are 3 by 6 feet and the plants are 1 to 2 feet in height. Most of them are from selected hybrids.



TWO-YEAR-OLD BLUEBERRY PLANT FROM A CUTTING.

The plant here shown is 18 inches high and is in a 3-inch pot. Its roots are matted at the wall of the pot, so that the root-ball is very firm and admirably adapted to shipment by mail. When photographed, in January, the plant was in its dormant condition, with fat fruit buds ready to produce flowers and berries in the plant's third year. The first season after transplanting, however, it is better not to allow the production of flowers and fruit but to concentrate the energy of the plant on the establishment of a good root hold.



BLUEBERRY FLOWERS.

Photograph, taken at Whitesbog, N. J., on May 12, of a vigorous blueberry twig just coming into flower. In the preceding autumn and winter this twig was unbranched and naked. Its upper seven buds were fat flowering buds, often called fruit buds. Those below were leaf buds. From each of the leaf buds has grown a leafy shoot, from each of the flowering buds a cluster of flowers. For the relation of the flower structure to pollination by bees, see page 17. (Natural size.)



EFFECT OF SELF-POLLINATION IN THE BLUEBERRY AS COMPARED WITH CROSS-POLLINATION.

These two twigs, both natural size, were in equally good situations on the same bush, contained the same number of flowers, all pollinated by hand at the same time with equal care, and the fruits were photographed on the same day. The only difference in treatment was that the pollen used on the left-hand twig came from other flowers on the same bush, while the pollen for the right-hand twig was taken from another bush. The cross-pollinated flowers produced a full cluster of handsome fruit. The self-pollinated flowers produced no ripe fruit, all the fruit that set remaining small and green and later dropping off, until at the time the photograph was taken only two such imperfect fruits remained. A plantation made up wholly from cuttings from a single bush would produce little or no fruit. At least two original propagation stocks are necessary.



FIG. 1.—PLANTATION OF 2-YEAR-OLD AND 3-YEAR-OLD HYBRID BLUEBERRIES AT WHITESBOG, N. J.

The soil is a white sand mixed with upland peat and is strongly and permanently acid. The rows are 8 feet apart, the plants 4 feet apart in the row. The row at the left consists of 3-year-old plants; the others are 2 years old. Each of these plants is a seedling hybrid, and although of carefully selected parentage its own qualities can not be known until it fruits. The photograph was taken August 2, 1917.



FIG. 2.—PLANTATION OF 5-YEAR-OLD AND 6-YEAR-OLD HYBRID BLUEBERRIES AT WHITESBOG, N. J.

From the same point as figure 1, above, but from a photograph taken three years later, on July 26, 1920. The plants in the left-hand row are now 6 years old, the others 5. In the background a blueberry packing shed has been erected. At the right in the background are shown the gauze screens that are placed over selected bushes which are to be kept under special observation.



FIG. 1.—BLUEBERRY CULTIVATION WITH A DISK HARROW.

Character of the work done with a disk harrow. This tool is especially adapted for use when grasses or other turf-forming weeds have invaded the plantation and the ground must be loosened deeply and thoroughly.



FIG. 2.—BLUEBERRY CULTIVATION WITH A SPRING-TOOTH HARROW.

The mellowing and good aeration accomplished in the white, sandy soil with the spring-tooth harrow is well shown in this figure. Shallow cultivation is at most times desirable in blueberry plantations, for the roots of the plants tend to make their principal development within a foot of the surface. The plants here shown are at 4-foot intervals in rows 8 feet apart.



FIVE-YEAR-OLD BLUEBERRY HYBRID.

This plant is a triple hybrid. One of the parents was a wild highbush blueberry from New Jersey, known as Rubel, with very large berries. The other parent was a hybrid bred from two large-berried wild plants from Greenfield, N. H., one of them a lowbush blueberry called Russell, the other a highbush blueberry named Brooks. The hybrid combines the sweetness of Russell, the delicious flavor of Brooks, and the large berry of Rubel. From its Russell grandparent it has inherited also medium earliness of fruiting and medium stature, being about 3 feet high when photographed.



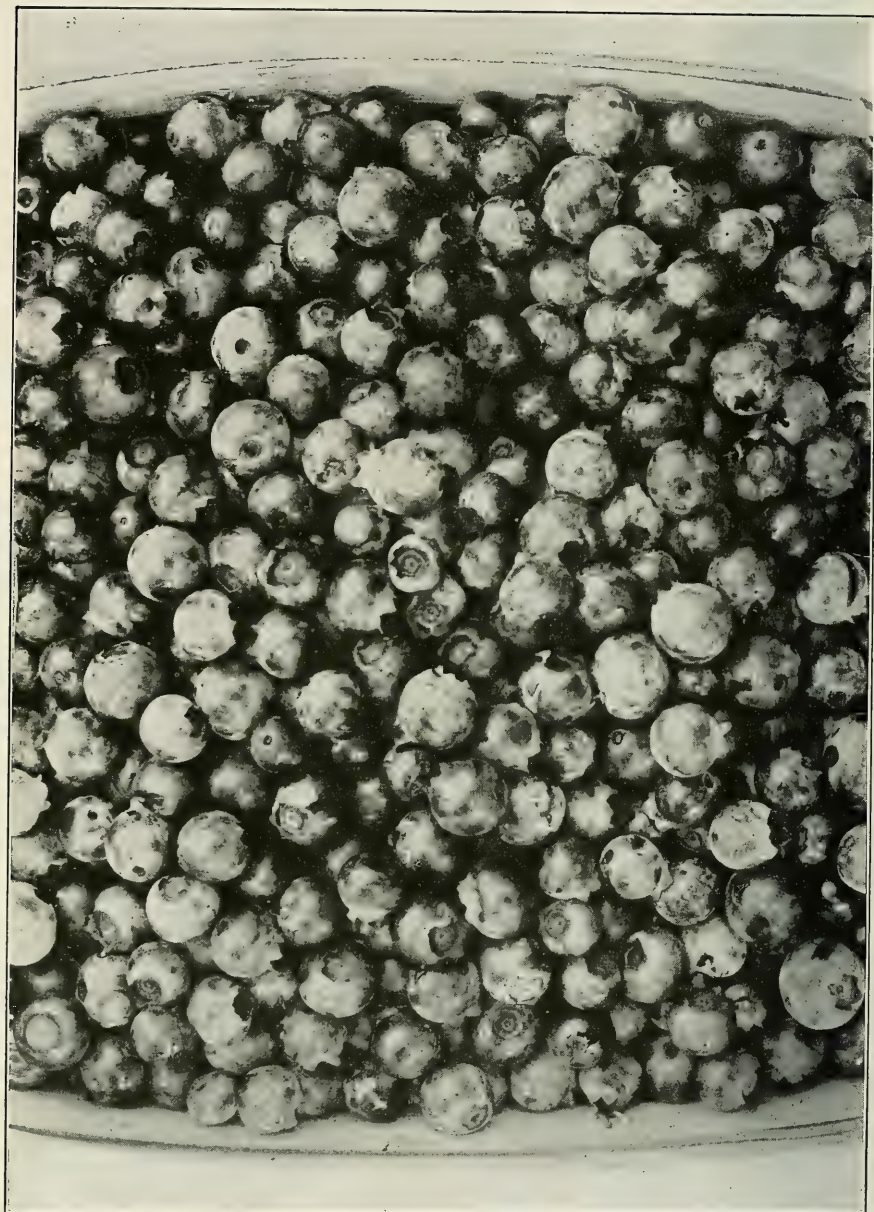
HANDSOME CLUSTER OF BLUEBERRIES FROM A REJECTED HYBRID.

Among the thousands of hybrids fruited at Whitesbog, N. J., hundreds produce berries as large and as handsome as these, yet although they are superior to all wild berries except the very best they are not regarded as of sufficiently high quality to merit selection and propagation when judged from the high standard set for hybrid blueberries. However, from unselected hybrid bushes of this class a yield of berries was obtained in 1919 at the rate of 96 bushels per acre. They sold at a little over \$10 a bushel, bringing gross receipts at the rate of \$966 per acre. In 1920 this planting yielded at the rate of 117 bushels per acre, which sold at a little less than \$11 a bushel, yielding gross receipts at the rate of \$1,280 per acre.



CLUSTER OF BLUEBERRIES FROM A SELECTED HYBRID.

From a photograph, taken on July 17, 1918, of a cluster of berries from a cultivated variety named Katharine. This is a selected hybrid, produced at Washington, D. C., and fruited at Whitesbog, N. J. Its parents are the Brooks blueberry, from Greenfield, N. H., and the Sooy blueberry, from Browns Mills, N. J., both of them wild plants of the high-bush type. (Natural size.)



THE ORDINARY WILD BLUEBERRY OF NEW JERSEY.

From a photograph, natural size, of a quart box of wild New Jersey blueberries, rather better than the average. It was taken for the purpose of comparison with the selected hybrid blueberries shown in Plate XXIX.



FRUIT OF THE KATHARINE BLUEBERRY, A SELECTED HYBRID.

The illustration shows, in its natural size, a quart box of hybrid blueberries of the same variety illustrated in Plate XXVII. The photograph represents the average product of the bush, for it was taken from a clean picking, including the small berries as well as the large ones.



BULLETIN No. 975

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A. C. TRUE, Director



Washington, D. C.



December 30, 1921

FOOD VALUES: HOW FOODS MEET BODY NEEDS.

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Society, and Lecturer, Teachers' College, Columbia University.*

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WHAT THE CHARTS SHOW.

The purpose of this bulletin is to bring out certain important and well-established facts by a new and graphic method. Up to this time the composition of foods has been presented to the housekeeper and the student chiefly by means of figures and in terms of percentages. This bulletin presents such facts not only in the older way but also by diagrams which should appeal quickly to the eye and be of assistance to the memory.

In estimating to what extent a certain food supplies the various substances required by the body or whether or not a diet meets the needs of the person who uses it, two sets of facts are needed—the kinds and amounts of substances required by the body, and the amounts of these substances supplied by different food materials. The more clearly these facts can be shown, the easier it is to plan satisfactory meals.

Through scientific research, the food needs of persons of different age, sex, and occupation are so well established that general statements can be made as to the number of calories of energy and the amount of protein, fat, and carbohydrates that should be provided for each. In this way have been gathered data about how much of these main nutrients and how much energy are furnished by the common food materials, and simple statements of these facts are

fairly common.¹ There are, however, other essentials in the diet which can not be explained so easily. For example, it has been difficult to make helpful statements about the mineral matters, the more important of which are iron, calcium, and phosphorus. It is fairly well known how much of these are needed by the body and how much are found in different food materials, but in both cases the quantities are so small (only a few grams or even milligrams per man per day or per pound of material) that it is impracticable to measure them by pounds or ounces as we do the food materials that supply them.

In general, the plan here followed is to make a graphic comparison between a pound of some of the common foods and the daily needs of a man who does moderately active muscular work. No one would think, of course, of trying to live on one food alone, but the comparison made by the charts is helpful in combining food materials so as to make a complete ration, for it shows not only what a given food supplies but also what it lacks. The milk diagram (p. 20) is a good illustration. A glance at it shows that a pound (pint) of milk would supply 9 per cent of the energy or fuel, 15 per cent of the protein, 80 per cent of the calcium, 32 per cent of the phosphorus, but only 7 per cent of the iron needed daily by a man who does moderately active muscular work. Or, to put it another way, if a pint of milk is used in the daily dietary of this man, the remaining foods must supply 91 per cent of the fuel needed, 85 per cent of the protein, 20 per cent of the calcium, 68 per cent of the phosphorus, and 93 per cent of the iron. To speak in particular only of the calcium and the iron, which offer a striking contrast, the remaining 20 per cent of the calcium would almost inevitably be supplied by the other foods even if they were selected at random, while it might require some thought to supply the other 93 per cent of the iron.

In making these comparisons it is assumed that the food supply of a man who does moderately active muscular work should furnish 3,500 calories of energy, or body fuel, 100 grams ($3\frac{1}{2}$ ounces) of protein, 0.68 gram of calcium, commonly called lime, 1.32 grams of phosphorus, and 15 milligrams of iron. This amount of food makes provision for waste, of which a certain amount is unavoidable. It is generally agreed that a properly nourished man doing moderately active muscular work eats daily food that supplies about 3,000 calories, and that to be sure of supplying this amount the foods provided for him should furnish about 3,500 calories. The allowance of 100 grams of protein provides a generous margin of safety above the actual protein requirement, and the allowances for calcium,

¹ U. S. Dept. Agr., Farmers' Bul. 142, Principles of Nutrition and Nutritive Value of Food; Farmers' Bul. 808, How to Select Foods. I. What the Body Needs.

phosphorus, and iron are slightly higher than what is considered a minimum requirement to cover possible waste and lack of utilization.

The needs of a man at moderately active muscular work are almost universally adopted as the unit for measuring food needs, and for this reason they are used in this publication. For some persons, it may be more to the point to know what percentage a given food supplies of the nutrients needed by the average adult, by the average family, or by some other individual or group. To change the percentages so that they will apply to the needs of the average adult, the man doing little or no muscular work, or the woman doing moderately active muscular work, they need only to be increased one-fourth. This must not be taken to mean that the man doing little or no work needs one-fourth more food than the man doing active work, but that he derives a higher proportion of the food needs of his body from a pound of a given food. For the woman doing little or no muscular work, they should be increased one-half. For the average family, which is supposed to consist of a man and a woman, both doing moderately active muscular work, and three young children, they should be only three-tenths as great. For example, a pound of oatmeal, which supplies 52 per cent of the fuel needed daily by a man at moderately active work, will supply $65 (1\frac{1}{4} \times 52)$ per cent of the fuel needed by the average adult, $78 (1\frac{1}{2} \times 52)$ per cent of the fuel needed by a woman who does little or no muscular work, and about $16 (\frac{3}{10} \times 52)$ per cent of the fuel needed by the average family. More detailed information on working out the energy requirements of various individuals and families is given in other publications of this department.¹

The charts will be found useful in various ways. The heavy lines, even without the figures that accompany them, show for what constituents the various foods are specially valuable. For example, the comparatively long lines representing iron in spinach, calcium in cheese, fuel in butter, phosphorus in peanuts, and protein in such foods as milk, eggs, and meat, show at a glance the nutrients in which these foods are rich.

The lines and figures also furnish an easy means of comparing one food with another. The energy lines on the sweet and Irish potato charts, for instance, show that the former has a higher fuel value. The protein lines on the oatmeal and rice charts show that as a source of protein, oatmeal excels rice. The calcium lines on the string bean and tomato charts show that the former is richer than the latter in lime. The phosphorus lines in corn and spinach show that corn is richer in this particular element. The iron line in lettuce as com-

¹ U. S. Dept. Agr., Farmers' Bul. 142, Principles of Nutrition and Nutritive Value of Food; Farmers' Bul. 1228, A Week's Food for an Average Family.

pared with that in turnips shows that lettuce is a better source of iron. By comparing the lines in the different charts in this way, a person can see what the various foods can be depended on to supply.

Not aways, however, is the body able to utilize equally well the nutritive elements present in different kinds of food. As will be discussed later, care must be used to select foods not only from a quantitative standpoint, but also with reference to digestibility, cost, dietary suitability, and the relative values of the types of protein, fat, carbohydrate, calcium, phosphorus, and iron which they may contain.¹

FOOD VALUES NOT SHOWN ON THE CHARTS.

In publishing these charts, which deal with food factors that can be measured by weight, there is no intention of undervaluing those other factors that can not be so measured, namely, the vitamins. Though the quantities of vitamins in different food materials have not yet been determined and the comparative vitamin values can not yet be satisfactorily expressed by lines or figures, general statements can be made in many cases and are given in connection with the charts.

Scientists now recognize at least three vitamins which, until more satisfactory names are agreed upon, may be called A, B, and C. Vitamin A is believed to be necessary for normal growth and development. It is sometimes known as fat-soluble A, because it is found associated with fat, and sometimes as the antirachitic vitamin, because when it is absent from the diet rachitis, or rickets, is likely to occur. It is found in milk, egg yolk, green-leaf vegetables, fats surrounding the vital organs of animals, and to a less extent in meat, and perhaps in certain fruits. Vitamin B is also believed to be necessary for general well-being. It is sometimes called water-soluble B, and sometimes the antineuritic vitamin, because lack of it may bring on polyneuritis, or beriberi. It is present in nearly all food materials except those that have been artificially purified, such as white sugar, white flour, and cornstarch, and most table oils. Vitamin C is sometimes known as water-soluble C, or as the antiscorbutic vitamin, because lack of it may be a cause of scurvy, or scorbut. It is found especially in certain fruits and vegetables, among them tomatoes, carrots, oranges, lemons, and grapefruit. It also occurs in fresh milk and probably in meat. Its efficacy in some foods seems to be easily destroyed by heat and sometimes by drying or even by ordinary storage, so that raw, fresh foods are in general the more reliable sources of it.

¹ The charts are based on average analyses published in *Chemistry of Food and Nutrition*, by H. C. Sherman, New York, 1918, and on additional data determined by Lucy H. Gillett at Columbia University.

ARRANGEMENT OF THE CHARTS.

The charts of the foods that resemble each other in certain important particulars are arranged in the five following groups: Vegetables and fruits; milk, eggs, cheese, and flesh foods; cereals and cereal preparations; sugar and sugary foods; and fats and fat foods.

Group I. VEGETABLES AND FRUITS.

(Charts 1-18, pp. 11-20.)

Vegetables and fruits are characterized by large percentages of mineral substances as compared with fuel and protein, and are important as furnishing bulk in the diet. Fruits that have been preserved by the addition of a large amount of sugar, whether in the form of rich preserves, jellies, jams, or marmalades, are not included in this group but with the sweets, for in such foods the mineral value is subordinated to the fuel value. The vegetables and fruits differ greatly among themselves in respect to the vitamins they supply, but the exact quantities supplied by each are not known. They also vary considerably with reference to the amount of water and inedible material in the pound as purchased and consequently in the amount of energy supplied.

The charts of vegetables and fruits are notable for the length of the lines representing mineral constituents as compared with those representing energy and protein. These lines show the basis for the familiar statement that vegetables and fruits are a good source of mineral substances in the diet. The reason for this is not that they contain more mineral substances per pound than other foods. In fact, as the charts show, they contain less in many cases. It is rather that these foods can be eaten in large amounts without danger of overloading the diet with protein and fuel. As an example of this, Irish potatoes (chart 1) may be compared with another starchy food, such as rice (chart 35). It takes only about $3\frac{1}{3}$ pounds, or 10 medium-sized, potatoes to furnish all the iron needed per man per day, and this amount of potatoes would supply only about 30 per cent of the needed fuel, leaving 70 per cent to be furnished by other common foods of the diet. Of rice, on the other hand, it would take nearly 4 pounds to supply the required amount of iron, and this quantity when boiled would measure at least 6 quarts and would alone furnish about twice the needed fuel.

A pound of the least watery kind in the fresh vegetable group, namely, sweet potatoes, as shown on page 12 (chart 2), would furnish about 13 per cent of the needed energy, and a pound of the one with the most water and inedible material, namely, muskmelon (chart 15), would furnish 3 per cent. Of the foods in Group II, on the other

hand, none supply less than 5 per cent, and several supply more than 50 per cent of the needed energy.

On the average, the fresh vegetables and fruits furnish per pound less than 6 per cent of the energy and protein needed, and 18, 13, and 23 per cent, respectively, of the calcium, phosphorus, and lime. In short, these foods are convenient for increasing mineral substances in the diet without increasing fuel beyond the desirable amount.

Dried beans, prunes, and raisins, all of which are, of course, far less watery than the fresh fruits, are shown in charts 16, 17, and 18, respectively. It should be noted, however, that as in the case of fresh vegetables and fruits, the lines representing calcium, phosphorus, and iron are long as compared with those representing fuel and protein. The dried vegetables and fruits, like the fresh vegetables and fruits, are important for supplying mineral substances. Dried beans are so rich in protein that they are often considered a meat substitute, but they differ from meat in some important particulars (see Group II).

The vegetables and fruits, particularly if uncooked, are almost without exception, important sources of vitamins in the diet. Practically all of them furnish vitamin B, which in fact is seldom lacking in the ordinary mixed diet; only in very one-sided diets consisting chiefly of polished rice or other refined cereals is it absent. The leaf vegetables, such as lettuce and spinach, supply vitamin A. Vitamin C, which is believed to prevent scurvy, is probably supplied by oranges and tomatoes better than by the other foods here shown. Potatoes, carrots, cabbage, and rutabagas are also sources of vitamin C.

The points to remember about foods in this group are:

- (1) Vegetables and fruits are useful in supplying mineral substances and bulk in the diet without unduly increasing protein and fuel.
- (2) All fruits and vegetables, even dried legumes which contain comparatively high proportions of protein, need to be supplemented by milk, eggs, cheese, and flesh foods.
- (3) Practically all vegetables and fruits are rich sources of one or more vitamins. The green-leaf vegetables are believed to be especially valuable sources of vitamin A, and oranges, lemons, and tomatoes of vitamin C.

Group II. MILK, EGGS, CHEESE, AND FLESH FOODS.

(Charts 19-30, pp. 21-26.)

Group II includes milk, eggs, cheeses of various kinds, meats except the very fattest, poultry, game, fish, sea foods, and also two of the legumes, namely, soy beans and peanuts, or, in general, all foods that contain efficient protein in amounts sufficient to supply at least one-sixth of their total fuel. These foods differ greatly among themselves in fatness and therefore in fuel value, in the amounts and kinds of minerals they contain, and also in their importance for supplying vitamins.

The foods of this group are characterized by comparatively large amounts of protein, as shown by the length of the second line on the charts. In this respect they resemble somewhat the cereals (Group III), except that in the cereals the other especially abundant nutrient is starch, whereas in the foods in Group II it is fat. The protein of the foods in Group II also differs from that of the cereals in being more adequate, or efficient, that is, more like body protein. Almost all the foods of this group are of animal origin. Peanuts and soy beans, of which the former only is shown here, are among the few exceptions. These foods differ from the other legumes, that is, dried beans, peas, and lentils, in containing efficient, or adequate, protein.

A given weight of fat yields the body over twice as much fuel as the same weight of protein, starch, or sugar, and the foods in Group II that show exceptionally long lines representing energy are those in which fat is especially abundant. Examples are beef and mutton (charts 24 and 25), cheese made from whole milk (chart 22), and peanuts (chart 30). Such long lines for energy suggest the wisdom of serving vegetables that have low fuel values with meats, of combining cheese with starchy foods such as macaroni, crackers, or rice rather than with such foods as butter or cream, and of making allowance for the fat of peanuts in combining them with other foods.

The comparatively short lines representing energy in the egg, cottage cheese, skimmed milk, and fresh codfish charts (charts 23, 21, 20, 27, respectively) are due to the small amount of fat they contain. The common custom of cooking eggs with butter, as in scrambling, or of serving them with bacon, or of serving codfish with sauces containing butter, egg yolks, or milk, compensates for the low proportion of fat and energy in these materials.

In comparing the various charts in this group, the small amount of iron in milk, cottage cheese, and fish and the rather large amount in eggs, beef, and mutton will be noted. Meats, though rich in iron, contain far less calcium, however, than milk and its products. These differences justify the use of eggs with milk as in custards, with cheese as in the baked dish known as cheese fondu, and with fish either in the form of slices of hard-boiled eggs or as an ingredient of a sauce. Since it is generally believed that the amount of calcium in the average diet runs very close to the lower limit of safety, the wisdom of using more milk and milk products than many people do is indicated.

Among the foods of this group, milk and egg yolks are most valuable in supplying vitamins A and B. Fresh raw milk is believed to provide the third, or antiscorbutic, vitamin, but its value in this

respect is low as compared with the juice of oranges, lemons, grapefruit, or tomatoes.

The points to remember about foods in this group are :

- (1) Milk, eggs, cheese, flesh foods, and the others of this group are the most important protein foods in the diet.
- (2) These are the foods that must be depended on for efficient protein, or, in other words, for the protein that can be used to special advantage by the body.
- (3) Milk is one of the best foods for young and old, and can not be satisfactorily replaced by any other food in the diet of growing children.
- (4) Some of these foods are rich in mineral substances, for example, meats and egg yolks in iron, milk in calcium, and peanuts in phosphorus.
- (5) Many of these protein foods, especially milk and egg yolks, are valuable sources of vitamins A and B.

Group III. CEREALS AND CEREAL PREPARATIONS.

(Charts 31-38, pp. 26-30.)

Cereals and their products contain comparatively large amounts of protein, usually associated with several times its weight of starch and, if the outer coatings of the grains are included, with vitamins and considerable amounts of mineral substances, particularly phosphorus. The protein, however, is not so efficient as that of the foods in Group II.

In all the charts representing cereals, the first and second lines are very nearly the same length. This indicates that in eating a given amount of cereal a person obtains about the same percentage of his needed energy as of his needed protein. A large slice of bread (1½ ounces), for example, supplies about 3 per cent of the fuel needed per man per day, and also about 3 per cent of the protein. Most people use more cereal foods than any other one kind. They generally use with the cereal foods some others, such as meat, eggs, or milk, which increase the protein, and still others, such as butter or sweets, which add to the energy value of the diet. Thus, in the ordinary mixed diet, the protein and the energy will probably bear the same proportion to each other that they do in the cereals.

The charts representing cereal foods differ far less one from another, particularly in the lines representing energy and protein, than those of any other group. As a matter of fact, the cereals themselves, which include wheat, oats, corn, rice, rye, and barley, differ very little in food value. The foods such as flour, meal, and breakfast foods that are made from cereals also differ very little, provided the same method of preparation is followed. For example, a whole-grain meal or breakfast food would have much the same composition whether it were made of corn, rice, wheat, or rye. On the other hand, a refined preparation of one cereal differs greatly, particularly in mineral substances, from a whole-grain preparation,

whether of that same cereal or some other. For example, white wheat flour is very different in composition from cracked wheat or brown rice.

It is necessary only to glance at the lines representing mineral substances in oatmeal and graham flour (charts 31 and 33), which contain nearly the entire grain, as compared with those in white flour (chart 32) from which the outer layers have been removed, to understand the theory that persons who can get few vegetables and fruits, which are rich in mineral substances, should use whole-grain rather than refined cereal foods.

The vitamine B is the chief one of the three vitamins provided by the cereal grains. It is found chiefly in the part of the grain near the germ; and when cereals, especially refined products, form the main part of the diet, care must be taken to provide vitamins from other sources, such as dairy products, vegetables, and fruits.

The points to remember about foods in this group are:

- (1) Cereals are the staple of the diet the world over because they are available almost everywhere, are easy to store and transport, and are relatively cheap.
- (2) Cereal foods provide protein and energy in about the proportions needed by the body. Their protein is, however, of such kind that it needs to be supplemented by that of milk, eggs, cheese, and flesh foods.
- (3) When made from the whole grains, cereal foods also supply some mineral substances and vitamins.
- (4) A diet containing large proportions of refined cereal foods must be supplemented by plenty of dairy products, vegetables, and fruits.
- (5) The various kinds of cereals used in the diet differ little in fuel value; rice, wheat flour, and cornmeal, for example, all yield about 1,600 calories to the pound.

Group IV. SUGAR AND SUGARY FOODS.

(Charts 39-42, pp. 30-32.)

Group IV includes sugar, sirup, molasses, honey, preserves, jellies, jams, marmalades, and candy, or, in general, all foods that furnish sugar chiefly.

The charts of this group show that sugar and foods consisting chiefly of sugar are mainly useful in supplying energy. Refined white sugar (granulated, lump, powdered, confectioners') is, in fact, all sugar. Brown and maple sugars, molasses, and maple sirup would show some protein and mineral matters, because they have some of the other ingredients of the juice or sap left in them. Dried prunes and raisins (charts 17 and 18) contain so much sugar that they are often grouped with the sugary foods. In addition to their energy, they contain mineral matters and some protein, as is natural considering that they are practically like fresh fruits except that most of the water has been removed. Jelly and preserved fruit

(charts 41 and 42) show some mineral matters and protein, but have relatively longer lines for energy because of the sugar used in preparing them. How much the efficacy of the vitamins survives drying and preserving is a question that has not yet been completely answered.

The group of sugary foods has another very important use—that of giving flavor to the diet, but this can not be expressed by lines on the diagrams.

The points to remember about foods of this group are:

- (1) Sugar and sugary foods are valuable for fuel and for flavor.
- (2) A few sweet foods, such as maple sirup, jelly, and preserved fruits, also contain small amounts of protein and mineral substances.
- (3) Sweets in proper amounts are an important part of the diet, provided they are served at such times as not to take away the appetite for other foods.

Group V. FATS AND FAT FOODS.

(Charts 43-48, pp. 32-35.)

In Group V are classed butter and other table fats; lard, suet, and other cooking fats; oil; bacon, salt pork, and pork sausage; chocolate; cream; fat nuts, which include all the common nuts but chestnuts; and in general, all foods in which fat supplies at least five-sixths of the total fuel, leaving only one-sixth to be supplied by protein, starch, or sugar. They differ greatly among themselves in respect to the minerals and vitamins they supply.

The length of the first line in the charts of this group, when compared with the first lines of the other charts, shows that, pound for pound, fats contribute more to the energy value of the diet than any other kind of food. The purified fats, such as lard (chart 43), show no lines except for energy. On the other hand, salt pork and chocolate (charts 46 and 47) show considerable protein; cream (chart 45) and chocolate, calcium; and all three, but particularly chocolate, show phosphorus. Chocolate also is a rich source of iron.

In comparing these foods with one another, it should be remembered that butter and cream are important for the vitamins that they furnish, especially vitamin A, and that these factors of the diet are almost if not entirely wanting in lard, table oils, and other artificially purified fats.

The points to remember about foods in this group are:

- (1) Fats and fat foods as a class have higher fuel value than those of any other group.
- (2) Fats add flavor and richness to the diet, but, since they are such concentrated fuel foods, are often used in excess of the amount needed.
- (3) Milk fat is a particularly rich source of vitamin A. Butter and cream are therefore far more important than most other fats in the diet of growing children.
- (4) Some of these fat foods, for example, chocolate and nuts, contain generous proportions of protein and mineral substances.

MISCELLANEOUS DISHES.

(Charts 49, 50, pp. 35, 36.)

Many of the "made dishes" that are prepared in the home or purchased in shops or restaurants contain materials from several of the five food groups. In estimating the food value of a meal, it is often convenient to consider these in the form in which they are eaten rather than by the separate items out of which they are made. This is done in the charts for cake and apple pie.

In chart 49 is represented a pound of rich cup cake, or somewhat over three-fourths of a cake made from the following ingredients: One-third of a cup of butter, 1 cup of sugar, $\frac{1}{2}$ cup of milk, 2 eggs, and $1\frac{5}{8}$ cups of flour. The cake as compared with apple pie (chart 50) is characterized by large amounts of protein and mineral substances due to the milk and eggs used in it. In this respect a chart representing lemon or custard pie would more nearly resemble the chart for cake.

NOTE.—In most of the following charts a line of a given length represents the same percentage value. In numbers 8, 16, 21, 22, 29, 30, 31, 33, 43, 47, and 48, however, one or more of the lines represent over 100 per cent of the daily requirement of the energy or nutrient specified, and in order to make room for this the scale has been somewhat reduced. For example, on p. 15, in chart 9, the base line represents 100 per cent, while in chart 8 represents 110 per cent.

Group I. VEGETABLES AND FRUITS.

Chart 1. ONE POUND OF IRISH POTATOES.

(3 medium-sized.)

A pound of Irish potatoes supplies about 315 calories of energy, 8 grams (about $\frac{1}{4}$ ounce) of protein, 0.05 gram of calcium, 0.2 gram of phosphorus, and 4.5 milligrams of iron. It would furnish, therefore, 9 per cent of the energy a man needs daily, 8 per cent of the protein, 7 per cent of the calcium, 16 per cent of the phosphorus, and 30 per cent of the iron. This is shown in the following chart:

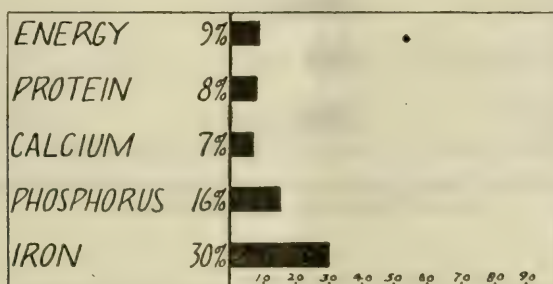


CHART 1.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of Irish potatoes.

Chart 2. ONE POUND OF SWEET POTATOES.

(2 large.)

A pound of sweet potatoes supplies about 445 calories of energy, 6 grams (about $\frac{1}{8}$ ounce) of protein, 0.07 gram of calcium, 0.15 gram of phosphorus, and 0.8 milligram of iron. It would furnish, therefore, 13 per cent of the energy a man needs daily, 6 per cent of the protein, 10 per cent of the calcium, 12 per cent of the phosphorus, and 12 per cent of the iron. This is shown in the following chart:

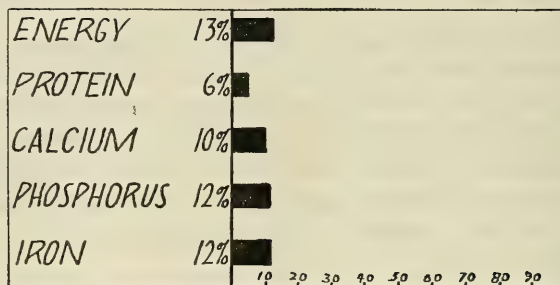


CHART 2.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of sweet potatoes.

Chart 3. ONE POUND OF ONIONS.

(4 or 5 medium-sized.)

One pound of onions supplies about 210 calories of energy, 6 grams (about $\frac{1}{8}$ ounce) of protein, 0.14 gram of calcium, 0.18 gram of phosphorus, and 2.2 milligrams of iron. It would furnish, therefore, 6 per cent of the energy a man needs daily, 6 per cent of the protein, 21 per cent of the calcium, 14 per cent of the phosphorus, and 15 per cent of the iron. This is shown in the following chart:

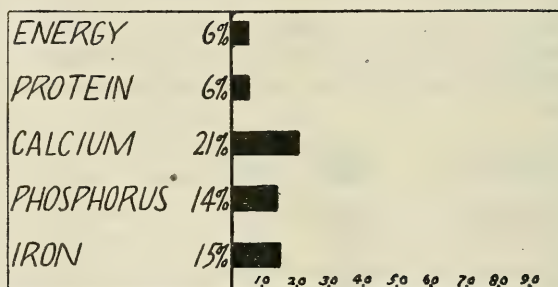


CHART 3.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of onions.

Chart 4. ONE POUND OF TURNIPS.

(3 or 4 medium-sized.)

A pound of turnips supplies about 140 calories of energy, 4 grams (about $\frac{1}{4}$ ounce) of protein, 0.2 gram of calcium, 0.14 gram of phosphorus, and 1.8 milligrams of iron. It would furnish, therefore, 4 per cent of the energy a man needs daily, 4 per cent of the protein, 30 per cent of the calcium, 11 per cent of the phosphorus, and 12 per cent of the iron. This is shown in the following chart:

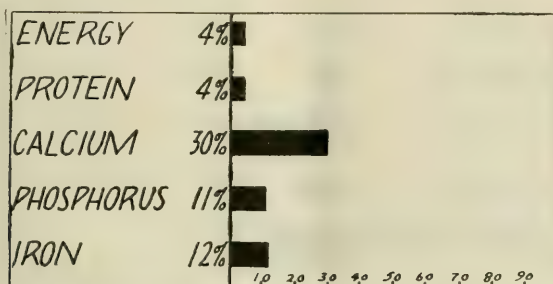


CHART 4.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of turnips.

Chart 5. ONE POUND OF ASPARAGUS.

(About 30 medium-sized stalks.)

One pound of asparagus supplies about 105 calories of energy, 8 grams (about $\frac{1}{4}$ ounce) of protein, 0.12 gram of calcium, 0.2 gram of phosphorus, and 4.5 milligrams of iron. It would furnish, therefore, 3 per cent of the energy a man needs daily, 8 per cent of the protein, 17 per cent of the calcium, 13 per cent of the phosphorus, and 30 per cent of the iron. This is shown in the following chart:

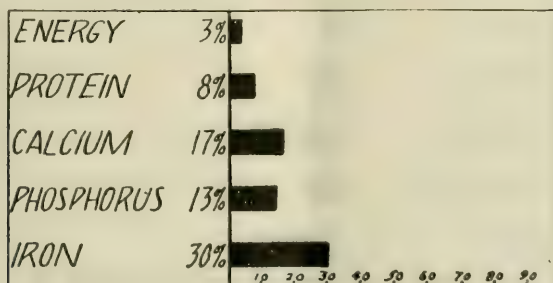


CHART 5.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of asparagus.

Chart 6. ONE POUND OF LETTUCE.

(2 large heads.)

One pound of lettuce supplies about 70 calories of energy, 5 grams (about $\frac{1}{8}$ ounce) of protein, 0.16 gram of calcium, 0.15 gram of phosphorus, and 2.7 milligrams of iron. It would furnish, therefore, 2 per cent of the energy a man needs daily, 5 per cent of the protein, 25 per cent of the calcium, 12 per cent of the phosphorus, and 18 per cent of the iron. This is shown in the following chart:

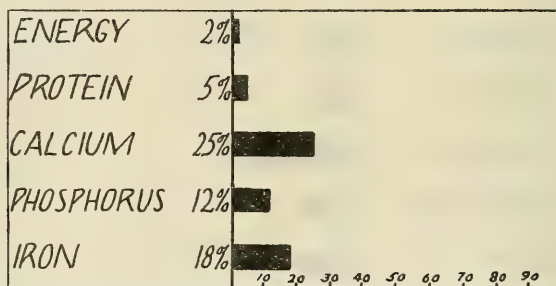


CHART 6.—Proportions of energy, protein, calcium, phosphorus and iron needed per man per day furnished by 1 pound of lettuce.

Chart 7. ONE POUND OF CABBAGE.

(About $\frac{1}{3}$ of an average head.)

One pound of cabbage supplies about 105 calories of energy, 6 grams (about $\frac{1}{8}$ ounce) of protein, 0.17 gram of calcium, 0.11 gram of phosphorus, and 4 milligrams of iron. It would furnish, therefore, 3 per cent of the energy a man needs daily, 6 per cent of the protein, 25 per cent of the calcium, 9 per cent of the phosphorus, and 27 per cent of the iron. This is shown in the following chart:

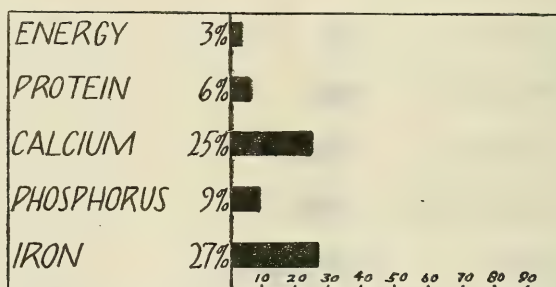


CHART 7.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of cabbage.

Chart 8. ONE POUND OF SPINACH.

(½ peck.)

One pound of spinach supplies about 105 calories of energy, 10 grams (about $\frac{1}{3}$ ounce) of protein, 0.3 gram of calcium, 0.3 gram of phosphorus, and 16 milligrams of iron. It would furnish, therefore, 3 per cent of the energy a man needs daily, 10 per cent of the protein, 45 per cent of the calcium, 23 per cent of the phosphorus, and 109 per cent (more than all) of the iron. This is shown in the following chart:

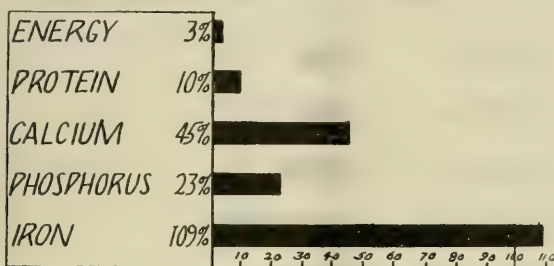


CHART 8.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of spinach.

Chart 9. ONE POUND OF STRING BEANS.

(About 1 quart.)

One pound of string beans supplies about 175 calories of energy, 6 grams (about $\frac{1}{3}$ ounce) of protein, 0.19 gram of calcium, 0.21 gram of phosphorus, and 4 milligrams of iron. It would furnish, therefore, 5 per cent of the energy a man needs daily, 6 per cent of the protein, 29 per cent of the calcium, 16 per cent of the phosphorus, and 27 per cent of the iron. This is shown in the following chart:

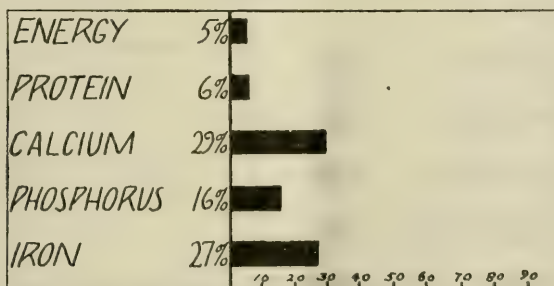


CHART 9.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of string beans.

Chart 10. ONE POUND OF GREEN CORN, CANNED.

(1½ cups.)

One pound of green corn, canned, supplies about 455 calories of energy, 13 grams (a little less than $\frac{1}{2}$ ounce) of protein, 0.14 gram of calcium, 0.5 gram of phosphorus, and 3 milligrams of iron. A pound of cooked fresh corn cut from the cob would supply practically the same quantities. Either would furnish, therefore, 13 per cent of the energy a man needs daily, 13 per cent of the protein, 21 per cent of the calcium, 38 per cent of the phosphorus, and 21 per cent of the iron. This is shown in the following chart:

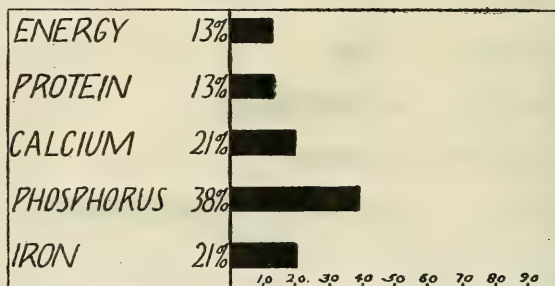


CHART 10.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of green corn, canned.

Chart 11. ONE POUND OF TOMATOES, CANNED.

(1½ cups.)

One pound of tomatoes, canned, supplies about 105 calories of energy, 5 grams (about $\frac{1}{4}$ ounce) of protein, 0.06 gram of calcium, 0.1 gram of phosphorus, and 1.8 milligrams of iron. It would furnish, therefore, 3 per cent of the energy a man needs daily, 5 per cent of the protein, 9 per cent of the calcium, 8 per cent of the phosphorus, and 12 per cent of the iron. This is shown in the following chart:

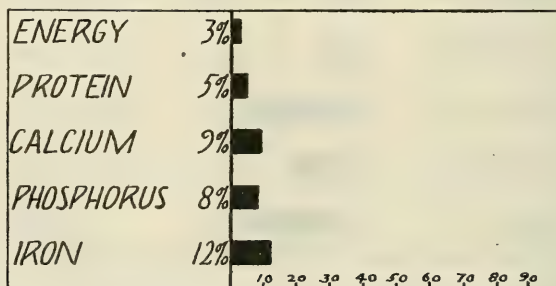


CHART 11.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of tomatoes, canned.

Chart 12. ONE POUND OF ORANGES.

(2 medium-sized.)

One pound of oranges supplies about 175 calories of energy, 3 grams (about $\frac{1}{8}$ ounce) of protein, 0.15 gram of calcium, 0.07 gram of phosphorus, and 0.9 milligram of iron. It would furnish, therefore, 5 per cent of the energy a man needs daily, 3 per cent of the protein, 22 per cent of the calcium, 5 per cent of the phosphorus, and 6 per cent of the iron. This is shown in the following chart:

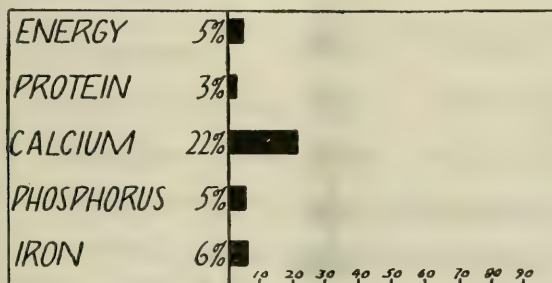


CHART 12.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of oranges.

Chart 13. ONE POUND OF APPLES.

(2 large.)

One pound of apples supplies about 210 calories of energy, 1 gram (an almost negligible amount) of protein, 0.02 gram of calcium, 0.04 gram of phosphorus, and 0.9 milligram of iron. It would furnish, therefore, 6 per cent of the energy a man needs daily, 1 per cent of the protein, 3 per cent of the calcium, 3 per cent of the phosphorus, and 6 per cent of the iron. This is shown in the following chart:

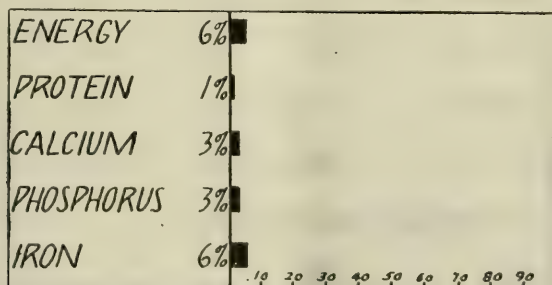


CHART 13.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of apples.

Chart 14. ONE POUND OF BANANAS.

(3 large.)

One pound of bananas supplies about 280 calories of energy, 4 grams (about $\frac{1}{4}$ ounce) protein, 0.02 gram of calcium, 0.09 gram of phosphorus, and 1.8 milligrams of iron. It would furnish, therefore, 8 per cent of the energy a man needs daily, 4 per cent of the protein, 4 per cent of the calcium, 7 per cent of the phosphorus, and 12 per cent of the iron. This is shown in the following chart:

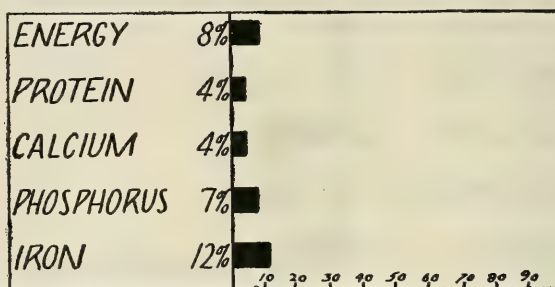


CHART 14.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of bananas.

Chart 15. ONE POUND OF MUSKMELON.

(1 medium-sized.)

One pound of muskmelon supplies about 105 calories of energy, 1 gram (an almost negligible amount) of protein, 0.04 gram of calcium, 0.03 gram of phosphorus, and 0.9 milligram of iron. It would furnish, therefore, 3 per cent of the energy a man needs daily, 1 per cent of the protein, 6 per cent of the calcium, 3 per cent of the phosphorus, and 6 per cent of the iron. This is shown in the following chart:

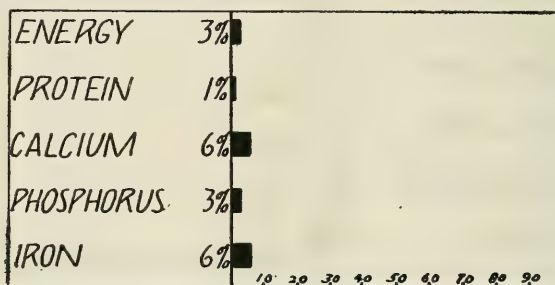


CHART 15.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of muskmelon.

Chart 16. ONE POUND OF DRIED BEANS.

(2½ cups.)

One pound of dried beans supplies about 1,575 calories of energy, 102 grams (about 3½ ounces) of protein, 0.7 gram of calcium, 2 grams of phosphorus, and 32 milligrams of iron. It would furnish, therefore, 45 per cent of the energy a man needs daily, 102 per cent of the protein, 107 per cent of the calcium, 162 per cent of the phosphorus, and 212 per cent of the iron. This is shown in the following chart:

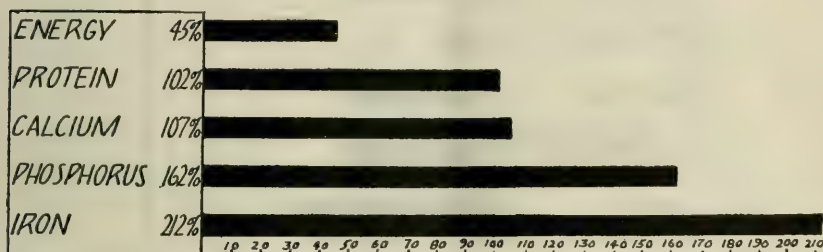


CHART 16.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of dried beans.

Chart 17. ONE POUND OF PRUNES.

A pound of prunes supplies about 1,155 calories of energy, 8 grams (about ¼ ounce) of protein, 0.2 gram of calcium, 0.4 gram of phosphorus, and 12 milligrams of iron. It would furnish, therefore, 33 per cent of the energy a man needs daily, 8 per cent of the protein, 31 per cent of the calcium, 31 per cent of the phosphorus, and 79 per cent of the iron. This is shown in the following chart:

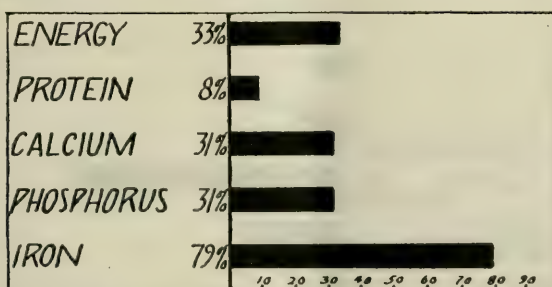


CHART 17.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of prunes.

Chart 18. ONE POUND OF RAISINS.

A pound of raisins supplies about 1,400 calories of energy, 10 grams (about $\frac{1}{3}$ ounce) of protein, 0.3 gram of calcium, 0.5 gram phosphorus, and 9 milligrams of iron. It would furnish, therefore, 40 per cent of the energy a man needs daily, 10 per cent of the protein, 39 per cent of the calcium, 41 per cent of the phosphorus, and 57 per cent of the iron. This is shown in the following chart:

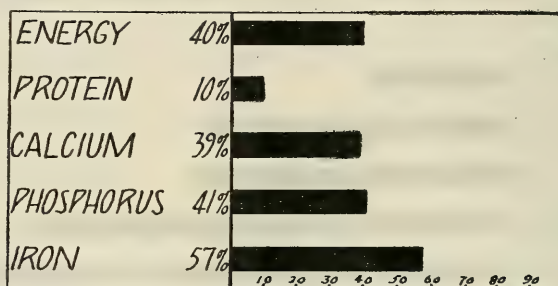


CHART 18.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of raisins.

Group II. MILK, EGGS, CHEESE, AND FLESH FOODS.

Chart 19. ONE POUND OF WHOLE MILK.

(2 cups.)

One pound of whole milk supplies about 315 calories of energy, 15 grams (more than $\frac{1}{2}$ ounce) of protein, 0.54 gram of calcium, 0.42 gram of phosphorus, and 1 milligram of iron. It would furnish, therefore, 9 per cent of the energy a man needs daily, 15 per cent of the protein, 80 per cent of the calcium, 32 per cent of the phosphorus, and 7 per cent of the iron. This is shown in the following chart:

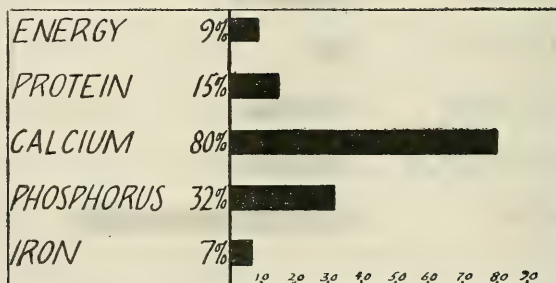


CHART 19.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of whole milk.

Chart 20. ONE POUND OF SKIMMED MILK.

(2 cups.)

One pound of skimmed milk supplies about 175 calories of energy, 15 grams (more than $\frac{1}{2}$ ounce) of protein, 0.55 gram of calcium, 0.43 gram of phosphorus, and 1 milligram of iron. It would furnish, therefore, 5 per cent, of the energy a man needs daily, 15 per cent of the protein, 81 per cent of the calcium, 33 per cent of the phosphorus, and 8 per cent of the iron. This is shown in the following chart:

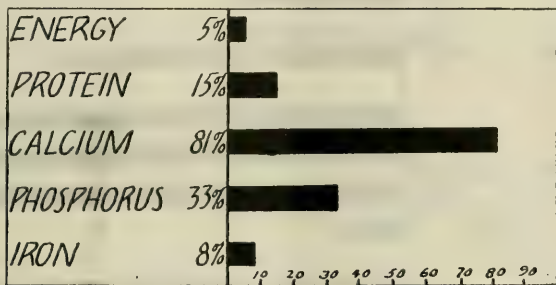


CHART 20.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of skimmed milk.

Chart 21. ONE POUND OF COTTAGE CHEESE.

(1½ cups packed solidly.)

One pound of cottage cheese supplies about 490 calories of energy, 95 grams (about $3\frac{1}{2}$ ounces) of protein, 0.45 gram of calcium, 1.5 grams of phosphorus, and practically no iron. It would furnish, therefore, 14 per cent of the energy a man needs daily, 95 per cent of the protein, 67 per cent of the calcium, 112 per cent (more than all) of the phosphorus, and none of the iron. This is shown in the following chart:

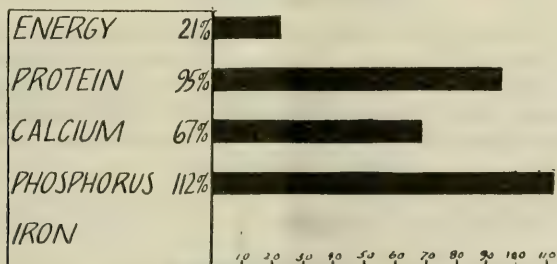


CHART 21.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of cottage cheese.

Chart 22. ONE POUND OF AMERICAN CHEESE.

One pound of American cheese supplies about 1,995 calories of energy, 131 grams (about 4½ ounces) of protein, 4.2 grams of calcium, 3.1 grams of phosphorus, and nearly 6 milligrams of iron. It would furnish, therefore, 57 per cent of the energy a man needs daily, 131 per cent of the protein, 621 per cent of the calcium, 235 per cent of the phosphorus, and 39 per cent of the iron. This is shown in the following chart:

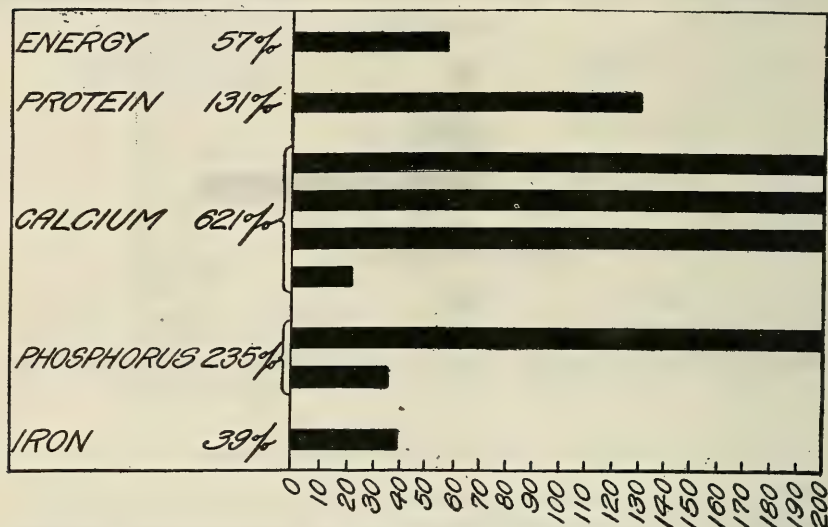


CHART 22.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of American cheese.

Chart 23. ONE POUND OF EGGS.

(8 to 10 medium-sized.)

One pound of eggs supplies about 595 calories of energy, 54 grams (about 2 ounces) of protein, 0.3 gram of calcium, 0.7 gram of phosphorus, and 12 milligrams of iron. It would furnish, therefore, 17 per cent of the energy a man needs daily, 54 per cent of the protein, 39 per cent of the calcium, 55 per cent of the phosphorus, and 82 per cent of the iron. This is shown in the following chart:

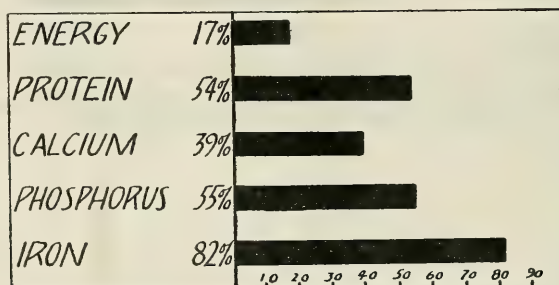


CHART 23.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of eggs.

Chart 24. ONE POUND OF BEEF.

One pound of medium fat beef, as purchased, supplies about 1,015 calories of energy, 67 grams (about 2½ ounces) of protein, 0.04 gram of calcium, 0.7 gram of phosphorus, and 11 milligrams of iron. It would furnish, therefore, 29 per cent of the energy a man needs daily, 67 per cent of the protein, 6 per cent of the calcium, 55 per cent of the phosphorus, and 74 per cent of the iron. This is shown in the following chart:

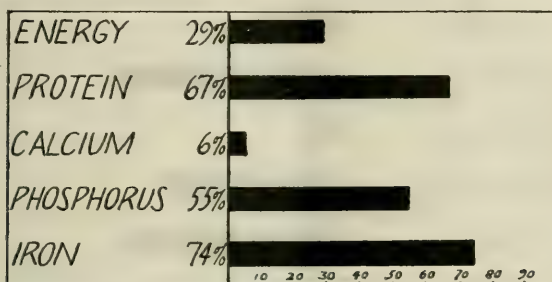


CHART 24.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of beef.

Chart 25. ONE POUND OF MUTTON.

One pound of average mutton, as purchased, supplies about 1,225 calories of energy, 59 grams (a little over 2 ounces) of protein, 0.03 gram of calcium, 0.6 gram of phosphorus, and 8.8 milligrams of iron. It would furnish, therefore, 35 per cent of the energy a man needs daily, 59 per cent of the protein, 5 per cent of the calcium, 48 per cent of the phosphorus, and 59 per cent of the iron. This is shown in the following chart:

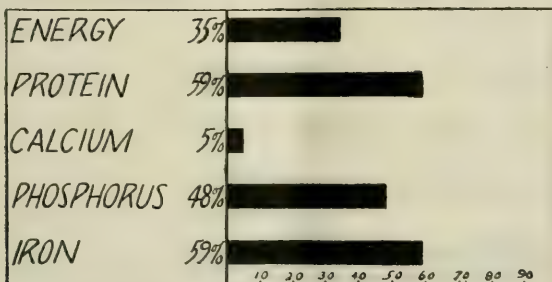


CHART 25.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of mutton.

Chart 26. ONE POUND OF FOWL.

One pound of fowl, as purchased, supplies about 735 calories of energy, 62 grams (about $2\frac{1}{4}$ ounces) of protein, 0.03 gram of calcium, 0.67 gram of phosphorus, and 9 milligrams of iron. It would furnish, therefore, 21 per cent of the energy a man needs daily, 62 per cent of the protein, 5 per cent of the calcium, 51 per cent of the phosphorus, and 62 per cent of the iron. This is shown in the following chart:

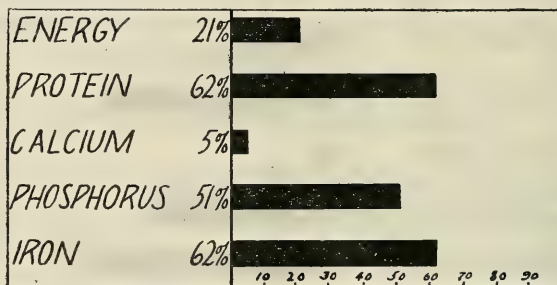


CHART 26.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of fowl.

Chart 27. ONE POUND OF FRESH CODFISH.

One pound of fresh codfish, as purchased, supplies about 175 calories of energy, 38 grams (about $1\frac{1}{3}$ ounces) of protein, 0.04 gram of calcium, 0.4 gram of phosphorus, and 2 milligrams of iron. It would furnish, therefore, 5 per cent of the energy a man needs daily, 38 per cent of the protein, 6 per cent of the calcium, 33 per cent of the phosphorus, and 14 per cent of the iron. This is shown in the following chart:

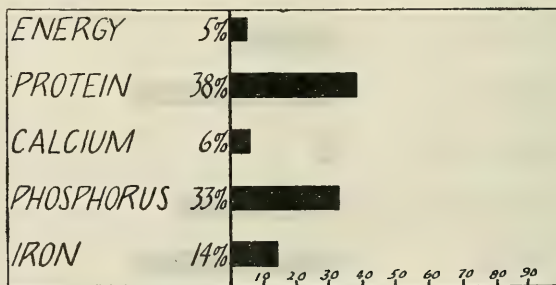


CHART 27.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of fresh codfish.

Chart 28. ONE POUND OF FRESH SALMON.

One pound of fresh salmon, as purchased, supplies about 630 calories of energy, 69 grams (about 2½ ounces) of protein, 0.07 gram of calcium, 0.8 gram of phosphorus, and 4 milligrams of iron. It would furnish, therefore, 18 per cent of the energy a man needs daily, 69 per cent of the protein, 11 per cent of the calcium, 60 per cent of the phosphorus, and 25 per cent of the iron. This is shown in the following chart:

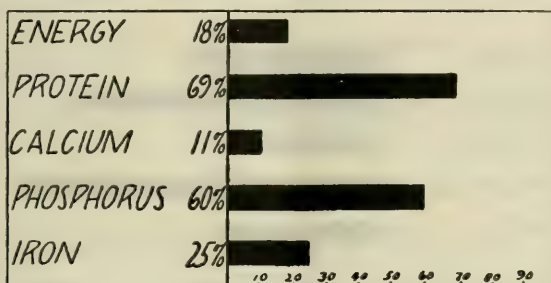


CHART 28.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of fresh salmon.

Chart 29. ONE POUND OF OYSTERS.

(About 1 pint.)

A pound of oysters supplies about 245 calories of energy, 28 grams (about 1 ounce) of protein, 0.2 gram of calcium, 0.7 gram of phosphorus, and 20 milligrams of iron. It would furnish, therefore, 7 per cent of the energy a man needs daily, 28 per cent of the protein, 35 per cent of the calcium, 53 per cent of the phosphorus, and 136 per cent (more than all) of the iron. This is shown in the following chart:

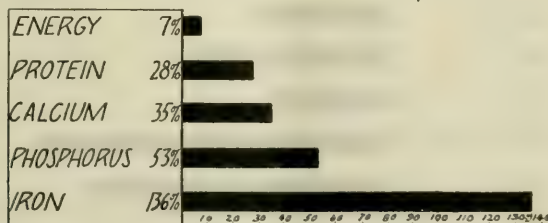


CHART 29.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of oysters.

Chart 30. ONE POUND OF SHELLED PEANUTS.

(24 cups.)

One pound of shelled peanuts supplies about 2,485 calories of energy, 117 grams (about $4\frac{1}{2}$ ounces) of protein, 0.3 gram of calcium, 1.8 grams of phosphorus, and 9 milligrams of iron. It would furnish, therefore, 71 per cent of the energy a man needs daily, 117 per cent of the protein, 47 per cent of the calcium, 137 per cent of the phosphorus, and 60 per cent of the iron. This is shown in the following chart:

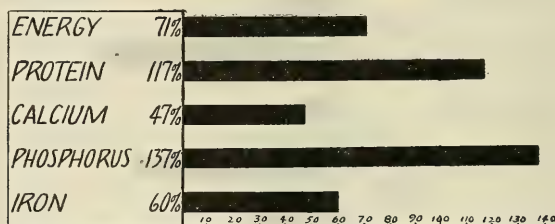


CHART 30.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of shelled peanuts.

Group III. CEREALS AND CEREAL PREPARATIONS.

Chart 31. ONE POUND OF OATMEAL.

(23 cups.)

One pound of oatmeal supplies about 1,820 calories of energy, 73 grams (more than $2\frac{1}{2}$ ounces) of protein, 0.3 gram of calcium, 1.8 grams of phosphorus, and 17 milligrams of iron. It would furnish, therefore, 52 per cent of the energy a man needs daily, 73 per cent of the protein, 46 per cent of the calcium, 135 per cent of the phosphorus, and 115 per cent of the iron. This is shown in the following chart:

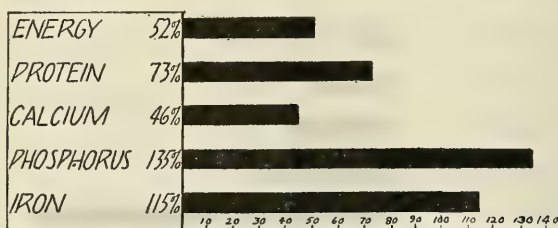


CHART 31.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of oatmeal.

Chart 32. ONE POUND OF WHEAT FLOUR.

(4 cups.)

One pound of wheat flour supplies about 1,610 calories of energy, 52 grams (nearly 2 ounces) of protein, 0.06 gram of calcium, 0.3 gram of phosphorus, and 3 milligrams of iron. It would furnish, therefore, 46 per cent of the energy a man needs daily, 52 per cent of the protein, 9 per cent of the calcium, 21 per cent of the phosphorus, and 21 per cent of the iron. This is shown in the following chart:

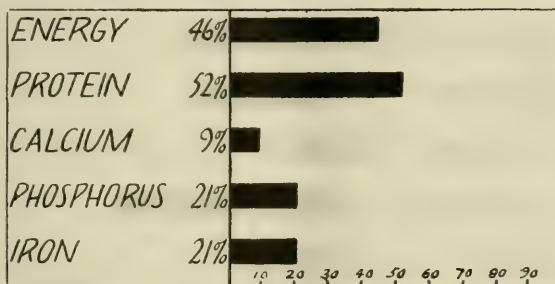


CHART 32.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of wheat flour.

Chart 33. ONE POUND OF GRAHAM FLOUR.

(4½ cups.)

One pound of graham flour supplies about 1,610 calories of energy, 60 grams (about 2 ounces) of protein, 0.17 gram of calcium, 1.6 grams of phosphorus, and 16.8 milligrams of iron. It would furnish, therefore, 46 per cent of the energy a man needs daily, 60 per cent of the protein, 26 per cent of the calcium, 125 per cent of the phosphorus, and 112 per cent of the iron. This is shown in the following chart:

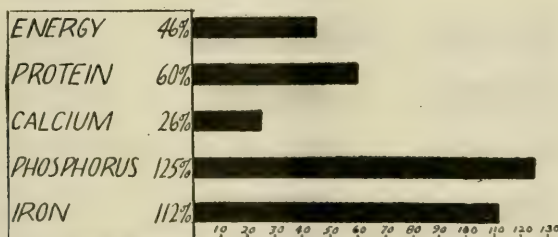


CHART 33.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of graham flour.

Chart 34. ONE POUND OF CORN MEAL.

(2½ cups.)

One pound of corn meal supplies about 1,575 calories of energy, 42 grams (about 1½ ounces) of protein, 0.08 gram of calcium, 0.9 gram of phosphorus, and 4 milligrams of iron. It would furnish, therefore, 46 per cent of the energy a man needs daily, 42 per cent of the protein, 12 per cent of the calcium, 65 per cent of the phosphorus, and 27 per cent of the iron. This is shown in the following chart:

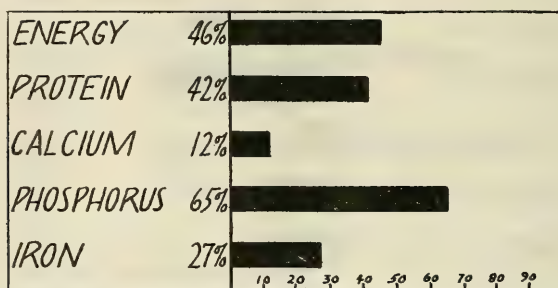


CHART 34.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of corn meal.

Chart 35. ONE POUND OF RICE.

(1½ cups.)

One pound of rice supplies about 1,610 calories of energy, 36 grams (about 1¼ ounces) of protein, 0.04 gram of calcium, 0.4 gram of phosphorus, and 4 milligrams of iron. It would furnish, therefore, 45 per cent of the energy a man needs daily, 36 per cent of the protein, 6 per cent of the calcium, 33 per cent of the phosphorus, and 27 per cent of the iron. This is shown in the following chart:

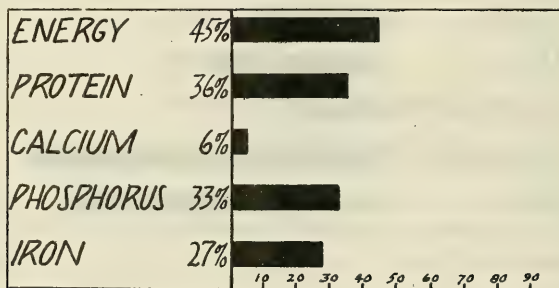


CHART 35.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of rice.

Chart 36. ONE POUND OF MACARONI.

One pound of macaroni, as purchased, supplies about 1,610 calories of energy, 61 grams (over 2 ounces) of protein, 0.1 gram of calcium, 0.6 gram of phosphorus, and 5.4 milligrams of iron. It would furnish, therefore, 46 per cent of the energy a man needs daily, 61 per cent of the protein, 15 per cent of the calcium, 49 per cent of the phosphorus, and 36 per cent of iron. This is shown in the following chart:

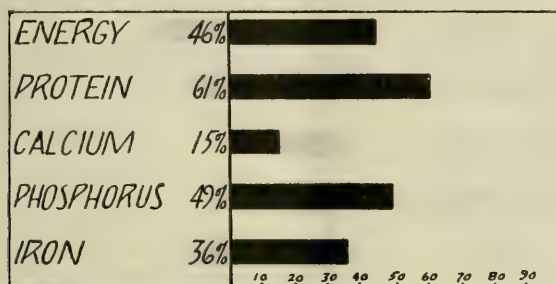


CHART 36.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of macaroni.

Chart 37. ONE POUND OF WHEAT BREAD.

($1\frac{1}{2}$ of an ordinary baker's loaf.)

One pound of wheat bread supplies about 1,190 calories of energy, 42 grams (about $1\frac{1}{2}$ ounces) of protein, 0.1 gram of calcium, 0.4 gram of phosphorus, and 4 milligrams of iron. It would furnish, therefore, 34 per cent of the energy a man needs daily, 42 per cent of the protein, 18 per cent of the calcium, 32 per cent of the phosphorus, and 27 per cent of the iron. This is shown in the following chart:

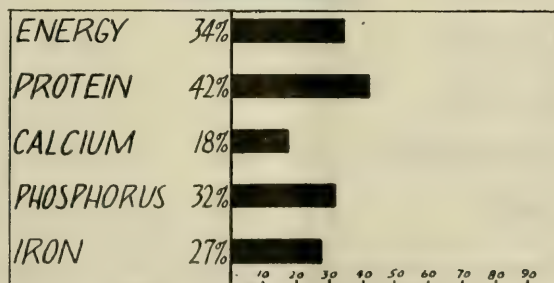


CHART 37.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of wheat bread.

Chart 38. ONE POUND OF "SODA" CRACKERS.

One pound of "soda" crackers supplies about 1,890 calories of energy, 44 grams (about 1½ ounces) of protein, 0.1 gram of calcium, 0.4 gram of phosphorus, and 6.7 milligrams of iron. It would furnish, therefore, 54 per cent of the energy a man needs daily, 44 per cent of the protein, 15 per cent of the calcium, 35 per cent of the phosphorus, and 45 per cent of the iron. This is shown in the following chart:

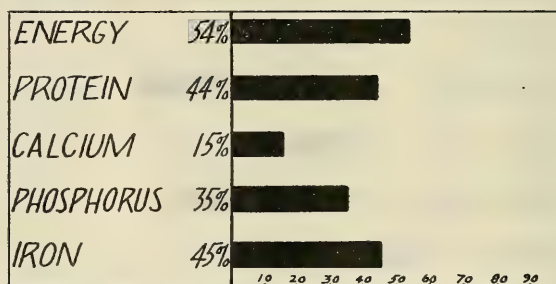


CHART 38.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of soda crackers.

Group IV. SUGAR AND SUGARY FOODS.

Chart 39. ONE POUND OF SUGAR.

(2 cups.)

One pound of sugar supplies about 1,820 calories of energy and contains none of the other substances included in these comparisons. It would therefore furnish 52 per cent of the energy a man needs daily. This is shown in the following chart:

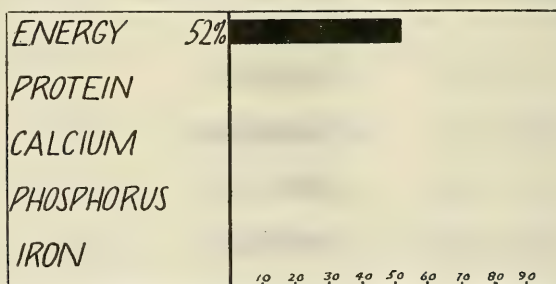


CHART 39.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of sugar.

Chart 40. ONE POUND OF HONEY.

(1½ cups.)

A pound of honey supplies about 1,470 calories of energy, 2 grams (about $\frac{1}{4}$ ounce) of protein, 0.02 grain of calcium, 0.09 gram of phosphorus, and 3 milligrams of iron. It would furnish, therefore, 42 per cent of the energy a man needs daily, 2 per cent of the protein, 3 per cent of the calcium, 7 per cent of the phosphorus, and 21 per cent of the iron. This is shown in the following chart:

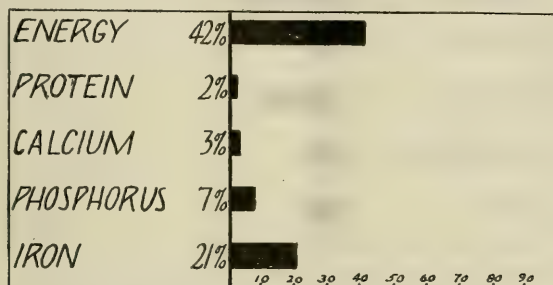


CHART 40.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of honey.

Chart 41. ONE POUND OF CURRANT JELLY.

A pound of currant jelly supplies about 1,190 calories of energy, 1 gram (a negligible amount) of protein, 0.06 gram of calcium, 0.04 gram of phosphorus, and 1 milligram of iron. It would furnish, therefore, 34 per cent of the energy a man needs daily, 1 per cent of the protein, 9 per cent of the calcium, 3 per cent of the phosphorus, and 9 per cent of the iron. This is shown in the following chart:

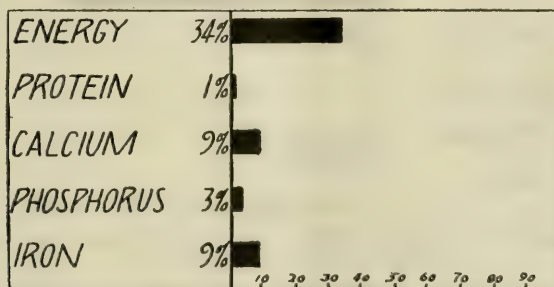


CHART 41.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of currant jelly.

Chart 42. ONE POUND OF PRESERVED BLACKBERRIES.

A pound of preserved blackberries supplies about 1,120 calories of energy, 4 grams (about $\frac{1}{2}$ ounce) of protein, 0.16 gram of calcium, 0.1 gram of phosphorus and 1 milligram of iron. It would furnish, therefore, 32 per cent of the energy a man needs daily, 4 per cent of the protein, 24 per cent of the calcium, 8 per cent of the phosphorus, and 9 per cent of the iron. This is shown in the following chart:

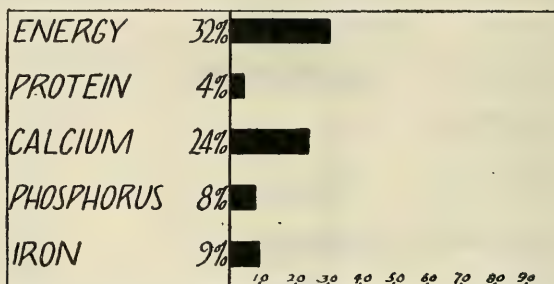


CHART 42.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of preserved blackberries.

Group V. FATS AND FAT FOODS.

Chart 43. ONE POUND OF LARD.

(2 cups.)

One pound of lard supplies about 4,100 calories of energy, and, if thoroughly refined, no other nutrients. It would furnish, therefore, 117 per cent, or considerably more than all the energy a man needs daily. This is shown in the following chart:

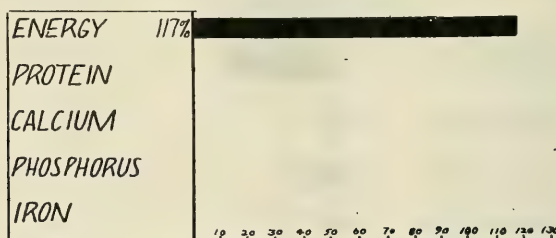


CHART 43.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of lard.

Chart 44. ONE POUND OF BUTTER.

One pound of butter supplies about 3,360 calories of energy, 5 grams (about $\frac{1}{4}$ ounce) of protein, 0.07 gram of calcium, 0.08 gram of phosphorus, and 1.8 milligrams of iron. It would furnish, therefore, 96 per cent of the energy a man needs daily, 5 per cent of the protein, 10 per cent of the calcium, 6 per cent of the phosphorus, and 6 per cent of the iron. This is shown in the following chart:

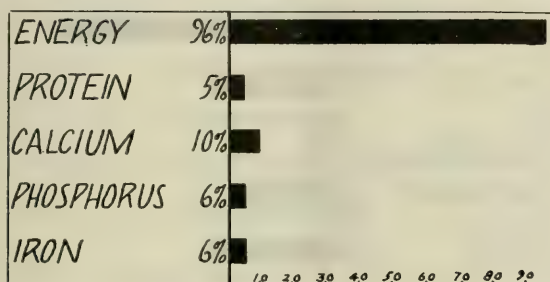


CHART 44.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of butter.

Chart 45. ONE POUND OF DOUBLE CREAM.

(About 2 cups.)

One pound of double cream supplies about 1,700 calories of energy, 9 grams (about $\frac{1}{4}$ ounce) of protein, 0.33 gram of calcium, 0.26 gram of phosphorus, and 0.5 milligram of iron. It would furnish, therefore, 49 per cent of the energy a man needs daily, 9 per cent of the protein, 49 per cent of the calcium, 20 per cent of the phosphorus, and 3 per cent of the iron. This is shown in the following chart:

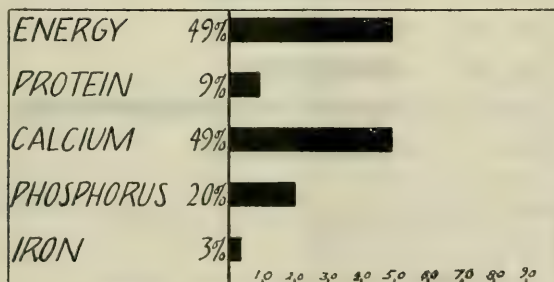


CHART 45.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of double cream.

Chart 46. ONE POUND OF FAT SALT PORK.

A pound of salt pork supplies about 2,835 calories of energy, 34 grams (about $1\frac{1}{8}$ ounces) of protein, 0.02 gram of calcium, 0.36 gram of phosphorus, and 5 milligrams of iron. It would furnish, therefore, 81 per cent of the energy a man needs daily, 34 per cent of the protein, 3 per cent of the calcium, 28 per cent of the phosphorus, and 34 per cent of the iron. This is shown in the following chart:

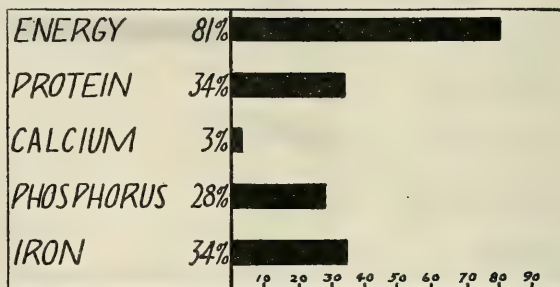


CHART 46.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of fat salt pork.

Chart 47. ONE POUND OF CHOCOLATE.

A pound of chocolate supplies about 2,765 calories of energy, 59 grams (about 2 ounces) of protein, 0.04 gram of calcium, 2 grams of phosphorus, and 12 milligrams of iron. It would furnish, therefore, 79 per cent of the energy a man needs daily, 59 per cent of the protein, 61 per cent of the calcium, 156 per cent (more than all) of the phosphorus, and 82 per cent of the iron. This is shown in the following chart:

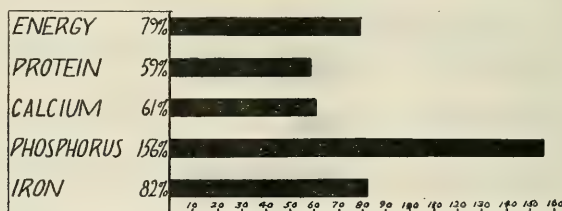


CHART 47.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of chocolate.

Chart 48. ONE POUND OF SHELLED WALNUTS.

One pound of shelled walnuts supplies about 3,185 calories of energy, 83 grams (nearly 3 ounces) of protein, 0.4 gram of calcium, 1.6 grams of phosphorus, and 9.6 milligrams of iron. It would furnish, therefore, 91 per cent of the energy a man needs daily, 83 per cent of the protein, 59 per cent of the calcium, 123 per cent (more than all) of the phosphorus, and 64 per cent of the iron. This is shown in the following chart:

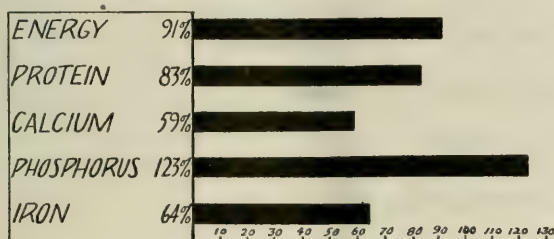


CHART 48.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of shelled walnuts.

Chart 49. ONE POUND OF "BUTTER" CAKE.

One pound of cake (representing seven-eighths of the following recipe: $\frac{1}{3}$ cup butter, 1 cup sugar, $\frac{1}{2}$ cup milk, 2 eggs, and $1\frac{1}{2}$ cups flour) supplies about 1,750 calories of energy, 29 grams (about 1 ounce) of protein, 0.2 gram of calcium, 0.3 gram of phosphorus, and 3 milligrams of iron. It would furnish, therefore, 50 per cent of the energy a man needs daily, 29 per cent of the protein, 31 per cent of the calcium, 23 per cent of the phosphorus, and 21 per cent of the iron. This is shown in the following chart:

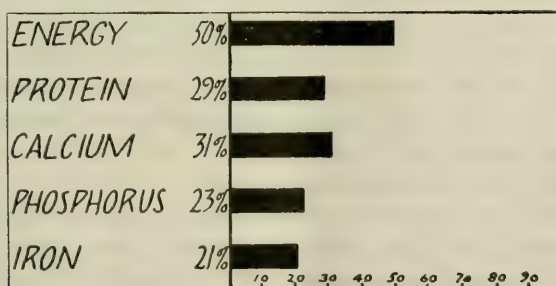


CHART 49.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of cake.

Chart 50. ONE POUND OF APPLE PIE.

One pound of apple pie supplies about 2,225 calories of energy, 14 grams (about $\frac{1}{2}$ ounce) of protein, 0.01 gram of calcium, 0.05 gram of phosphorus, and 0.9 milligram of iron. It would furnish, therefore, 35 per cent of the energy a man needs daily, 14 per cent of the protein, 3 per cent of the calcium, 4 per cent of the phosphorus, and 6 per cent of the iron. This is shown in the following chart:

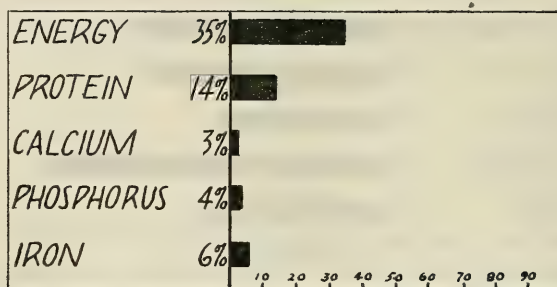


CHART 50.—Proportions of energy, protein, calcium, phosphorus, and iron needed per man per day furnished by 1 pound of apple pie.

USES OF THE CHARTS.

The housekeeper or the student of foods can quickly see from the charts in just what proportions the five important constituents—fuel, protein, calcium, phosphorus, and iron—are supplied in 50 common foods. The charts are so simply arranged that a cursory reading will show these special characteristics of the various foods. For example, even a glance at the chart of American cheese will show that it is extremely rich in calcium. If desired, additional charts may be constructed easily for other foods by using the figures for the nutritive requirements (p. 2) in relationship to the amount of energy, protein, calcium, phosphorus, and iron present in the foods as reported in tables showing food composition.³

The charts show how far a pound of any one of the foods goes toward supplying the fuel, protein, calcium, phosphorus, and iron needed daily by a man at moderate muscular work. The percentages of these constituents supplied by fractions of a pound can easily be calculated. Changes may also be made to indicate the relationship of a certain quantity of food to the requirements of a family or to a period of time longer than a day.

How much of several different foods will be needed to supply the daily requirement of iron or any other element, can be found by adding the percentages representing this element.

³ U. S. Dept. Agr., Office Expt. Sta. Bul. No. 28, Chemical Composition of American Food Materials.

Another use for the charts is in showing what foods can be combined to make a complete ration. For a complete ration the sum of the energy from all the foods included should equal 100 per cent, and similarly with protein, calcium, phosphorus, and iron. Although there is no disadvantage and probably considerable advantage if the totals for calcium, phosphorus, and iron are higher than those for energy and protein. The completeness of a ration can be tested by adding together the percentages of the constituents shown on the charts. In classroom or lecture use it may be more effective to fill in the lines on a skeleton chart as the different foods making up a ration are discussed. Allowance must also be made for bulk and vitamins. As pointed out on page 4, these are necessary elements of the diet although they can not be definitely measured.

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August 17, 1921

A STUDY OF THE FACTORS
AFFECTING TEMPERATURE CHANGES
IN THE CONTAINER DURING THE
CANNING OF FRUITS AND
VEGETABLES

By

C. A. MAGOON and C. W. CULPEPPER
Office of Horticultural and Pomological Investigations

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Fruit Improvement through Bud Selection:

A. D. Shamel.

C. S. Pomeroy.

B. E. Caryl.

Nut-Production Investigations:

C. A. Reed.

E. R. Lake.

M. N. Wood.

Fruit and Vegetable Storage Physiology:

L. A. Hawkins.

R. C. Wright.

J. R. Magness.

G. F. Taylor.

J. F. Fernald.

H. C. Diehl.

Nursery-Stock Investigations:

L. B. Scott.

G. L. Yerkes.

Extension Work (in cooperation with States Relations Service):

W. B. Beattie.

C. P. Close.

UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 957

Contribution from the Bureau of Plant Industry
WM. A. TAYLOR, Chief

Washington, D. C.

PROFESSIONAL PAPER

February 6, 1922

INVESTIGATIONS OF THE WHITE-PINE
BLISTER RUST

By

PERLEY SPAULDING, Pathologist,
Office of Investigations in Forest Pathology

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UNITED STATES DEPARTMENT OF AGRICULTURE
BULLETIN No. 963

Contribution from the Office of Farm Management and Farm Economics
H. C. TAYLOR, Chief

In Cooperation with the Bureau of Plant Industry
W. A. TAYLOR, Chief

Washington, D. C.

September 21, 1921

COST OF PRODUCING SUGAR BEETS
IN UTAH AND IDAHO, 1918-1919

By

L. A. MOORHOUSE, Associate Farm Economist,
Office of Farm Management and Farm Economics

and

S. B. NUCKOLS, Agriculturist, Sugar-Plant Investigations,
Bureau of Plant Industry

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SUMMARY OF RESULTS

Number of farm records averaged, 220.

Range in cost of sugar beets per ton, \$5 to \$35.

Two out of the 220 growers produced their beets at the minimum cost, \$5 per ton.

The one grower who produced beets at the maximum cost, \$35, harvested but 3 tons per acre.

Seventy-three per cent of the growers produced beets at a cost of \$11 per ton or less.

Average cost, \$9.49 per ton. Costs were above this level on nearly half the farms.

Labor constituted 69 to 75 per cent of all costs exclusive of land rent; material, 7 to 10 per cent; and insurance, taxes, overhead, etc., 17 to 30 per cent.

UNITED STATES DEPARTMENT OF AGRICULTURE
BULLETIN No. 965

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C.

October 18, 1921

CONTROL OF THE ARGENTINE ANT IN
CALIFORNIA CITRUS ORCHARDS

By

R. S. WOGLUM, Entomologist, and A. D. BORDEN, Scientific
Assistant, Fruit Insect Investigations

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DEPARTMENT BULLETIN No. 973



Washington, D. C.



June 5, 1923

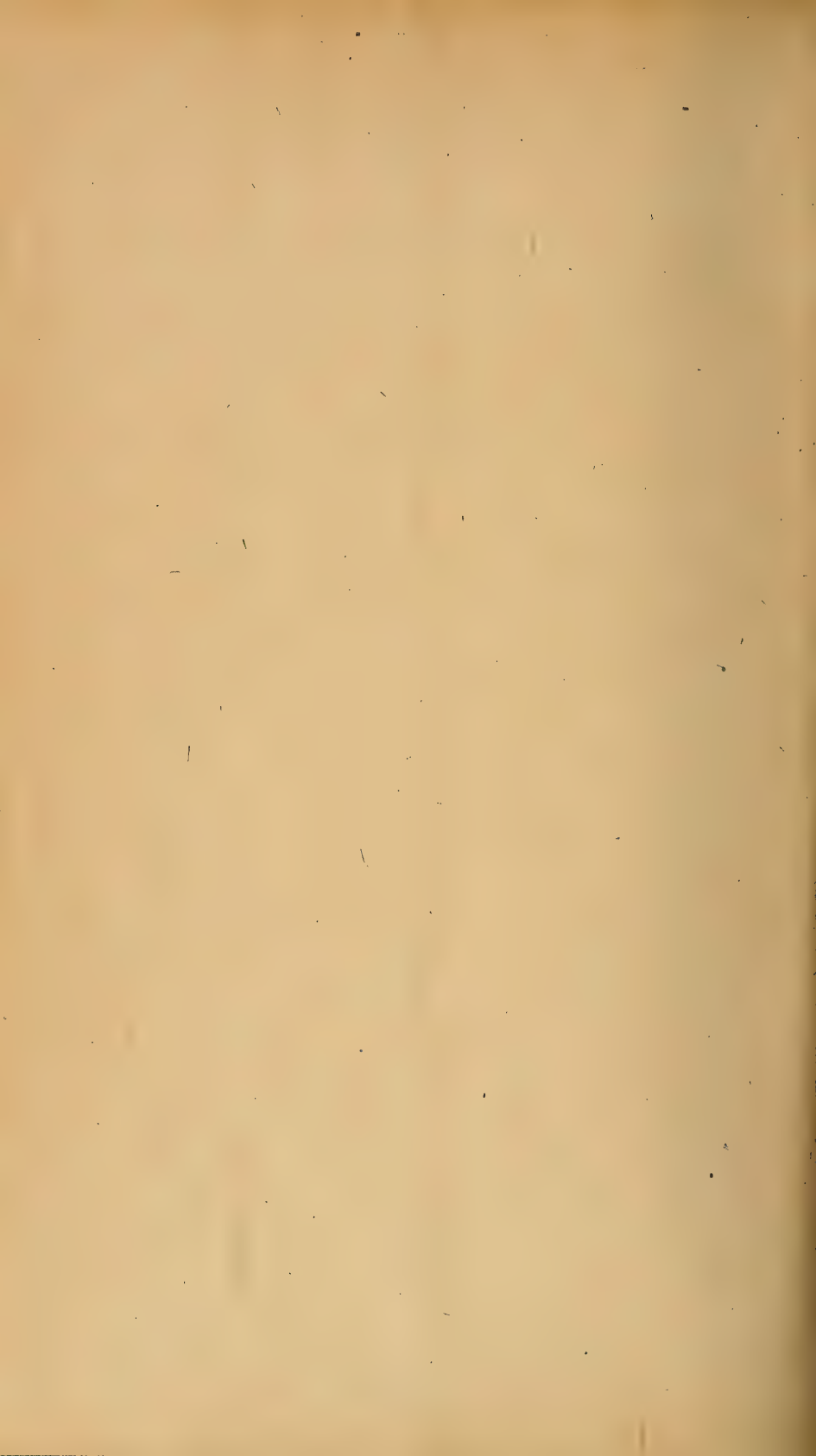
MILK-PLANT OPERATION

By

CLARENCE E. CLEMENT, Market Milk Specialist, Dairy Division,
Bureau of Animal Industry

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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 974

Contribution from the Bureau of Plant Industry
WM. A. TAYLOR, Chief

Washington, D. C.

PROFESSIONAL PAPER

October 15, 1921

DIRECTIONS FOR BLUEBERRY
CULTURE, 1921

By

FREDERICK V. COVILLE, Botanist

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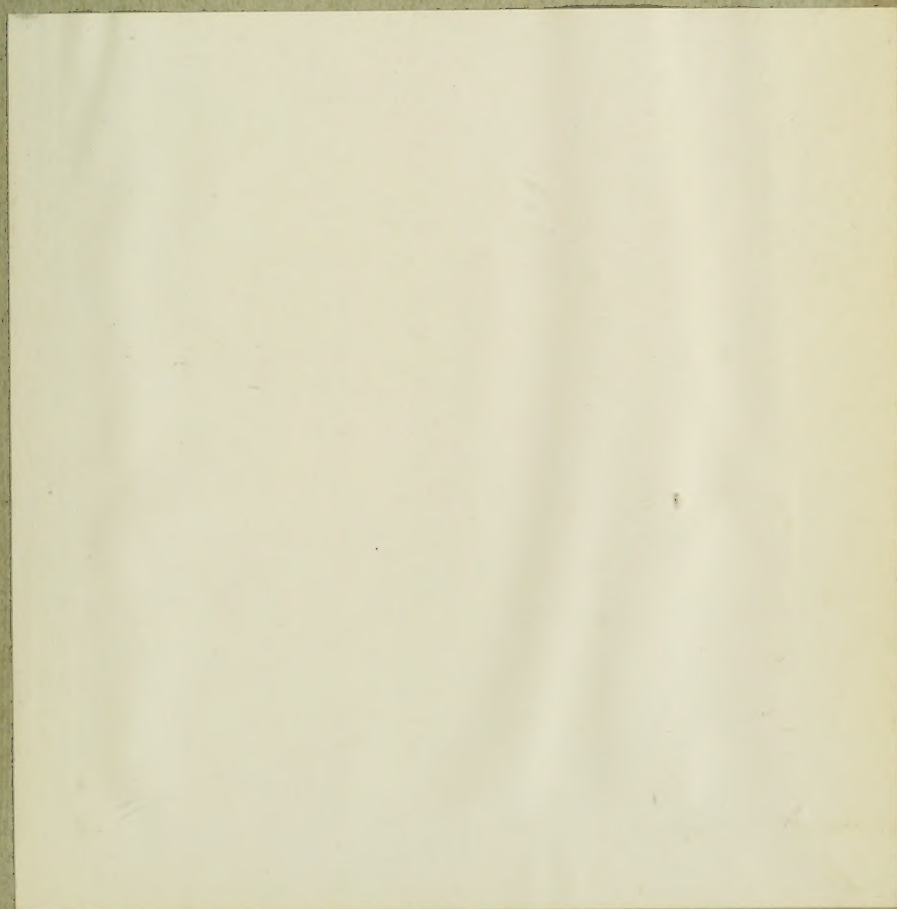


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